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OMPHALIA ROOT ROT OF THE DATE PALM[1,2]

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INTRODUCTION

THE IMPORTANCE of omphalia root rot (*9*),[4] or decline disease,[5] to the date industry lies principally in the fact that affected areas are increasing both in size and in number. About 1 per cent of the total acreage devoted to date culture in the Coachella Valley of California has become affected, and the annual loss in fruit production from this source at the present time may approach 100,000 pounds. With the exception of fruit spoilage, omphalia root rot is the most destructive fungus disease of date palms in California. Because this disease is comparatively new to science and because only a few of the date gardens are affected, the menace which it presents is as yet not fully appreciated. If one may judge by the present condition of certain plantings, however, it could, over a period of many years, become a limiting factor in the date industry.

Since certain date growers are urging control of omphalia root rot through regulation of planting stock, it is desirable to publish at this time a comprehensive report on the investigations of this disease, covering a period of fifteen years. Several preliminary papers (*4, 5, 6, 7, 9, 10, 11*) have appeared, but there are extensive experimental data and numerous illustrations not heretofore published. With special emphasis on these new data, this paper presents a summary of present knowledge concerning the omphalia root rot.

HISTORY

From the information now available, it seems that omphalia root rot was unknown before 1921, when one stunted palm was noticed. Little attention was given the matter until other, near-by palms showed a similar tendency. By 1927 there was evidence that palms previously normal in appearance had lost vigor and had become worthless. The trouble was first called to the attention of the University of California Citrus Experiment Station by officials of the United States Date Garden, Indio, California. A preliminary survey by H. S.

[1] Received for publication December 4, 1942.

[2] Paper No. 497, University of California Citrus Experiment Station, Riverside, California.

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[4] Italic numbers in parentheses refer to "Literature Cited" at the end of this paper.

[5] After much study it became apparent that most of the injury associated with the so-called "decline disease," if not all of it, was due primarily to root decay caused by two species of *Omphalia* (*O. pigmentata* Bliss and *O. tralucida* Bliss), and at the suggestion of H. S. Fawcett, the writer proposed the name "omphalia root rot" (*11*).

Fawcett revealed groups of similarly affected palms in four other gardens within a radius of a few miles.

Apparently all the first-known cases of the disease involved palms of the Deglet Noor variety, which had originated as offshoots in French North Africa and had been planted in the Coachella Valley about 1915. The symptoms of omphalia root rot were first noted when the palms from these importations

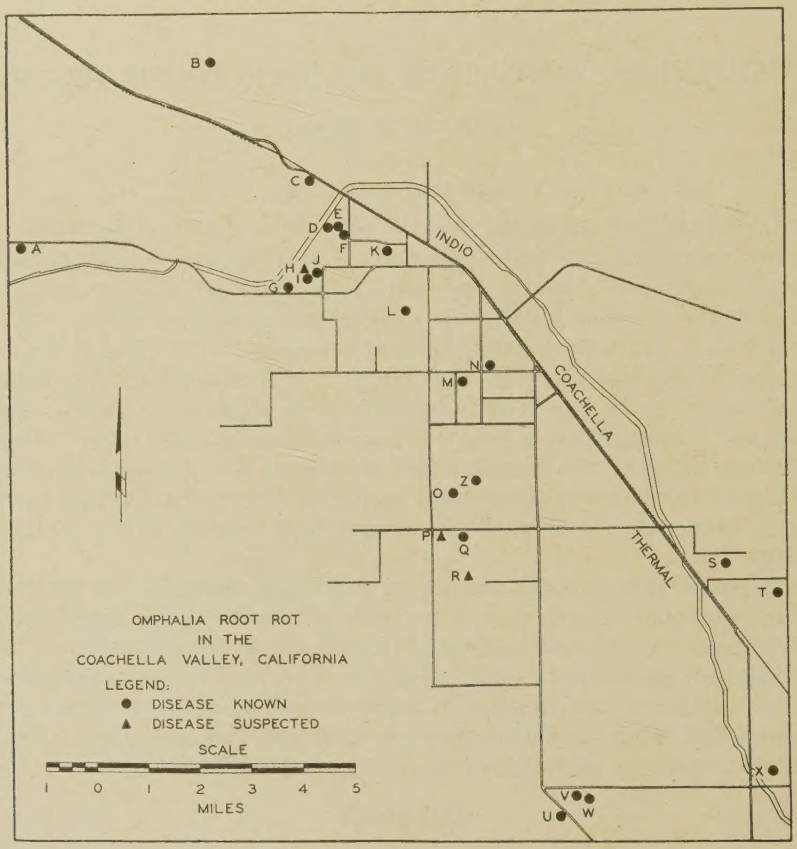


Fig. 1.—Locations of date gardens in the Coachella Valley, California, where omphalia root rot is known or suspected. The letters are those used in referring to these gardens elsewhere in the paper.

began to fruit. The potential seriousness of the trouble was not realized, however, until the affected date gardens reached the stage of maximum fruit production.

The first published reference to this disease appeared in the Report of the California Agricultural Experiment Station for 1928–29 (*15*). It mentioned that a study was being made of "a slow deterioration of date palms in local areas with loss of fruiting." In 1930 Klotz (*36*) referred to omphalia root rot as "the stunted growth disease or slow failure or degeneration disease." He suggested that it was due either to fungi or to faulty nutrition. Haas and

Klotz (*29*) were the first to use the name "decline disease." They reported that many roots of affected palms had deteriorated.

Origin.—The origin of omphalia root rot is not known. Two possibilities are suggested: First, the disease may have been introduced to California on date palms from the Old World; second, the disease may occur on some of the native vegetation in the Coachella Valley of California and may have spread to the date palms since their introduction to this country.

Distribution.—So far as is known, omphalia root rot is limited to California. Except for a single case[6] near Riverside, California, this root rot of date palms has been found only in the Coachella Valley, which lies in the south central portion of Riverside County.

The principal date-growing region in the Coachella Valley is included in an area 10 miles wide and 25 miles long, lying northwest of the Salton Sea. In 1940, the estimated acreage of dates (*3*) was 3,014, or about 2 per cent of the area mentioned above. The date gardens, estimated at over 200, are scattered singly or in small groups throughout the valley. Twenty-three different properties are known to be affected with omphalia root rot, and in three others the disease is suspected (fig. 1). Its occurrence has not been related to soil type or to any other geographic character.

SYMPTOMATOLOGY

The characteristic symptoms of omphalia root rot develop after the attack of either of two fungi, *Omphalia pigmentata* or *O. tralucida*, which differ distinctly in botanical characteristics but which cause similar necrotic lesions in the date palm. The following description of the symptoms of omphalia root rot is therefore applicable to the effect caused by either species or by a combination of both.

The symptoms of this disease may be classified as *primary* and *secondary*. Primary symptoms are the conditions resulting from the pathological processes of omphalia root rot on parts actually invaded by the pathogens; secondary symptoms are the indirect effects of the disease on parts usually at some distance from the site of mycelial invasion. All organs of the date palm are apparently subject to attack, but those parts below the soil line are usually the only ones invaded. This is attributed to the unfavorable moisture conditions surrounding the aerial portions of the palm.

PRIMARY SYMPTOMS

The primary symptoms of omphalia root rot are of the necrotic type (plate 1 and fig. 2). Lesions occur on leaf bases, roots, and trunk, where environmental conditions permit. Usually, no lesions form above the soil line. A slightly brownish discoloration of the epidermis is the first visible manifestation of the disease. Some of the underlying cells become brown and necrotic before mycelial penetration begins. As the fungus develops, the lesion enlarges and tissues of all kinds are affected. Sometimes the surface becomes depressed, but it is believed that lesions commonly originate where there is no wound to serve as an infection court.

[6] A Saidy palm which had been obtained as an offshoot in 1931 from a date garden in the Coachella Valley, near Indio, was found to be affected with omphalia root rot.

The tender root tip is very susceptible to attack. Roots may also be affected near, or at some distance from, their point of attachment to the trunk (plate 1). These lesions are more or less localized, but they usually involve all the different tissues from the epidermis to, and including, the tissues of the central cylinder. Since the conductive vessels of the root are plugged with masses of tightly woven mycelium, it seems that the normal functions of the root must be seriously impaired, though the pathogen may be found only in a limited

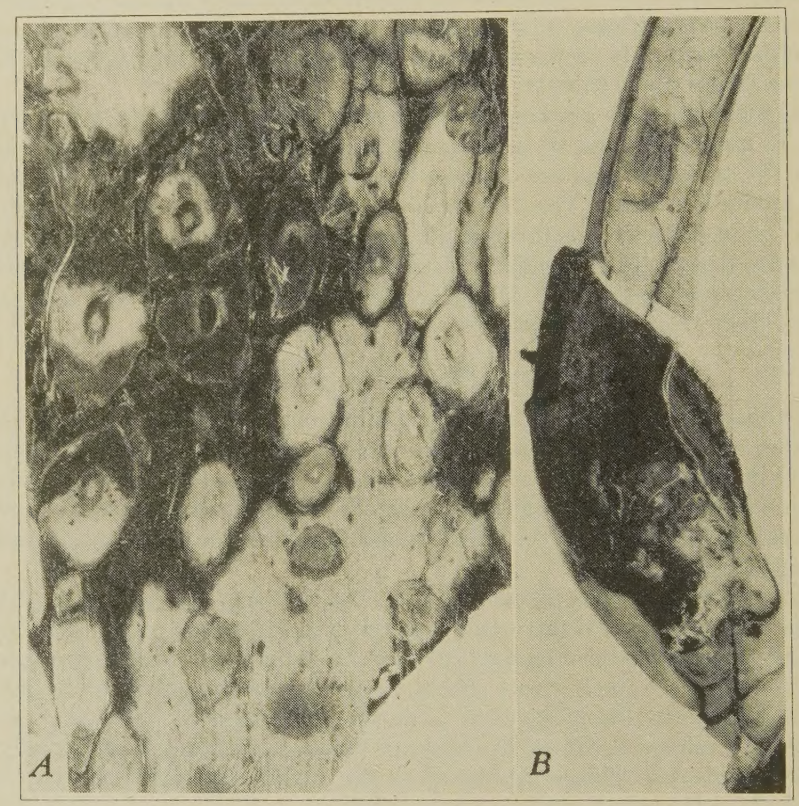


Fig. 2.—Omphalia root rot in Deglet Noor offshoots: *A*, tangential section through the root zone of the trunk where *Omphalia tralucida* had caused extensive necrosis; *B*, rhizomorphs and mycelial mats of *O. pigmentata* between the leaf bases.

region. Lesions in young roots appear somewhat reddish to lead-colored on the outer surface. Inside, the invaded tissue is dark brown and separated from the healthy tissue by a zone of yellowish, dying cells.

The disease does not cause rapid decomposition in the cellular structure of the roots. At first the fungus penetrates the cell walls and tends to fill the cortical cavities (plate 6 and p. 55) with white masses of mycelium that are sometimes visible to the naked eye (fig. 3). Invaded tissue is comparatively dry, except where the soil is saturated with moisture. Necrotic tissues undergo a gradual decay and disorganization, which is attended in the final stages by

the invasion of other microörganisms from the soil. The cortical tissue disappears first and leaves the outer integument and central cylinder for later disintegration.

Root-rot lesions appear to be most common about the base of the trunk, where there is usually a tangle of roots and dead leaf bases mixed with soil. *Omphalia* spp. develop readily on various types of dead organic material if moisture is available. The dead leaf bases and fiber at the base of a date palm supply a favorable medium for the production of a large amount of mycelium, a condition which must be reached before the pathogen is capable of attacking the roots. Young roots are commonly infected and aborted (plate 1) before

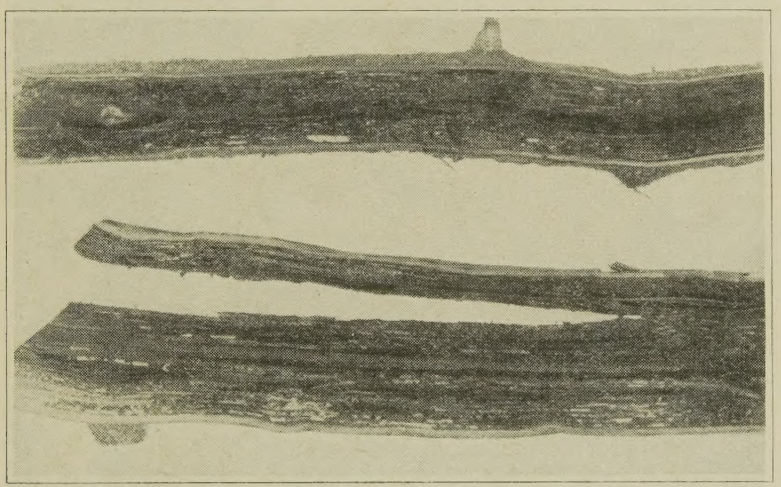


Fig. 3.—Masses of the white mycelium of *Omphalia tralucida* in the cortex of necrotic roots. These small white streaks are useful in diagnosing the disease.

they succeed in penetrating the dead leaf-base material between the trunk and the soil. This is perhaps the most damaging type of injury produced.

Lesions in the trunk are usually associated with the bases of diseased roots (plate 1). Mycelial invasion of the trunk may come directly from a root or from the juncture of the root with the rind of the trunk. Such lesions are comparatively superficial. None have been observed to penetrate more deeply than the outer 1-inch layer. Such necrosis undoubtedly prevents the development of other primary roots whose buds have formed within this region of the trunk.

Another type of injury involves the offshoots that originate as vegetative buds in the axils of certain leaves, most of which are situated in the lower whorls. When the vascular connection between parent and offspring is in the root zone, the offshoot is vulnerable to attack by omphalia but, occasionally, when this connection is above the soil level, an offshoot may escape infection because of its position. When offshoots are saved for propagation, they are retained on the mother palm for several years and commonly strike root. During this period they may become badly infected with omphalia (fig. 2).

Small offshoots may show lesions on the leaf bases. Ropelike bundles of fungus hyphae, known as "rhizomorphs," penetrate the spaces between the

leaf bases and then spread out in fan-shaped crusts (fig. 2, *B*). The leaf surfaces to which the fungus adheres become discolored and necrotic. Later, the fungus gains entrance and spreads slowly through the tissues. The white mycelium of omphalia may be found in considerable quantities on the surface of the underground parts or may be lacking. Because of the similarity in appearance of omphalia and some other soil fungi, it is not safe to rely entirely on this character in diagnosing the disease.



Fig. 4.—General view of an omphalia-root-rot area in garden *T*. The palms are of the Deglet Noor variety. (Photograph by Avery Edwin Field.)

SECONDARY SYMPTOMS

The occurrence of primary symptoms of omphalia root rot may be followed by profound changes in the appearance of the aerial portions of the date palm. Such changes are classified as secondary symptoms because they are thought to represent only the effects of the morbid condition below ground. A knowledge of secondary symptoms is of practical importance in detecting and diagnosing omphalia root rot.

One of the first visible symptoms of omphalia root rot (*4*) is premature wilting, which results in the death of leaves in the lower whorls (fig. 4). On large palms which stand at the advancing edge of an omphalia-root-rot area, a considerable number of leaves on the side facing the area may die before any distress can be noticed on the opposite side (fig. 5). The life of leaves of healthy

palms is from three to four years. Omphalia root rot tends to reduce both the length of life and also the rate at which new leaves appear. Where a comparison with healthy palms of similar age could be made (figs. 6 and 7), it has been



Fig. 5.—Deglet Noor palm on the advancing margin of an omphalia-root-rot area, showing the premature wilting and death of many leaves on the side facing the diseased area. (Photograph by Avery Edwin Field.)

determined that the reduction in the number of green leaves has amounted in some cases to 90 per cent. Normally, on healthy palms a few of the lower leaves turn brown and die each year during the warmer months; but on diseased palms, a much larger number of leaves may die within a few weeks during July, August, and September, when very high temperatures prevail. The leaves turn brown throughout their length more quickly than when dying



Fig. 6.—Healthy, seventeen-year-old Deglet Noor palm. Notice the large, rounded top and the height of the trunk in comparison with the 10-foot measuring stick. (Photograph by Avery Edwin Field.)

from natural causes, and the blades become tough and shrunken as they bend downward.

An unnatural yellow-green cast appears in leaves of Deglet Noor date palms that are affected with omphalia root rot. The size of the leaf is reduced. The petiole is narrow and weak, and the midrib and pinnae are slender and shortened.

The retardation of terminal growth is another conspicuous symptom of



Fig. 7.—Diseased, seventeen-year-old Deglet Noor palm. This palm and the one shown in figure 6 were obtained as offshoots from Algeria in 1913. They were planted in 1915 in the same row of garden *T* and received uniform treatment. Retarded terminal growth and a small, brushlike top are conspicuous secondary symptoms of omphalia root rot. (Photograph by Avery Edwin Field.)

omphalia root rot. Vigorous palms of the Deglet Noor variety (fig. 8) may grow 2 to 3½ feet annually. This rate is gradually reduced as the disease develops. Whereas the trunk of a tree having the first visible symptoms may elongate 10 to 15 inches in a year, the trunk of a badly affected palm may grow 6 inches or not at all (fig. 9). A convenient method for determining

yearly growth is that of measuring, vertically, the distance between the bases of the fruitstalks of successive years. By October, the distance between the base of the current year's fruitstalks and the highest visible fiber line represents the greater part of trunk elongation for the year (see fig. 8). These

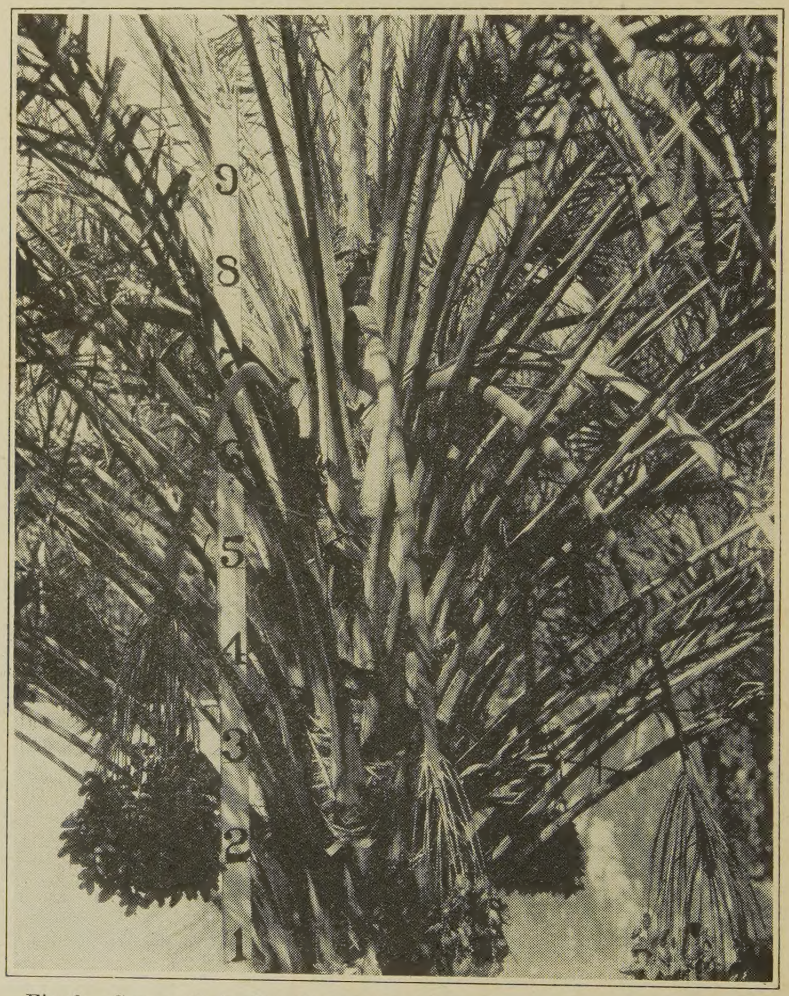


Fig. 8.—Crown of a healthy Deglet Noor palm. Carrying more than 100 green leaves and 200 pounds of ripening fruit, this palm illustrates the vigorous condition that is associated with health. The distance between the base of the fruit stalks and the fiber line indicates an annual growth rate of nearly 3 feet. (Photograph by Avery Edwin Field.)

outward signs of growth are presumably an indication of activity in the terminal bud, from which all the aboveground organs originate. In extreme cases of omphalia root rot, the height of the terminal bud does not seem to increase from year to year; as a result, the bases of the young leaves are at approximately the same level as those of older leaves.

Vegetative vigor in date palms is reflected by the size and number of fruit

bunches produced. In a garden of Deglet Noor palms, healthy trees are found commonly with 12 to 18 bunches of dates, whereas those infected with omphalia will have less than 10. (A few spathes usually appear each year even on the weakest palms.) The fruitstalks of sick palms are narrow and weak in com-



Fig. 9.—Crown of a severely diseased Deglet Noor palm. Terminal growth has nearly ceased. All of the 34 green leaves arise from the trunk within a vertical distance of 1 foot. A small crop of commercially worthless dates has been produced. (Photograph by Avery Edwin Field.)

parison with those of healthy palms. In extreme cases the fruitstalks of diseased palms are not more than 1 inch in width and are so weak that a small load of fruit will break them. The flowers of diseased palms are apparently normal to the extent that they are receptive to pollination. The fruits (fig. 10, *C*) that develop are practically worthless, however, because they are hard, fibrous, shriveled at the tip, and undersized. Palms showing early symptoms of disease

produce fruit of intermediate quality. From the commercial viewpoint, the quantity and quality of fruit produced are the principal factors to be considered. Since omphalia root rot is accompanied by a marked decrease in the



Fig. 10.—Deglet Noor dates as affected by omphalia root rot: *A*, fruit bunches from (*a*) healthy, (*b*) severely diseased, and (*c*) moderately affected palms; *B*, fruits from a healthy palm; *C*, fruits from a diseased palm.

amount of fruit produced and by a decline in quality, it is apparent that affected palms are unprofitable.

At first, the symptoms of omphalia root rot were not recognized in palms prior to the fruiting stage. When the causal fungi and the primary symptoms of the disease were discovered, however, the slowness of growth, lack of green

leaves, and unthrifty appearance of certain young palms could be explained. Artificial inoculation of small seedling date palms with *Omphalia* spp. has thrown additional light on this subject.

Seedling palms up to one year in age are often killed by these fungi because of necrotic lesions formed on the roots and leaf bases and in the basal node. In such cases the secondary symptoms are the rapid wilting and death of the leaves, beginning with the oldest leaves on the outside and progressing inward. The seedling may be killed outright or it may survive in a more or less stunted condition. Since the leaves of the date palm contain much silica, they retain a certain degree of stiffness even when completely wilted. The juvenile leaves are simple undivided blades with a number of veins running parallel to the longitudinal axis. The wilting of these grasslike leaves resembles the folding of a fan in which the ribs remain stiff while the interveinal portions become flaccid. The color of the wilted leaf is at first pale green, then silver, and finally light brown. In older palms in which the green leaves are attached to the trunk above the soil line, *Omphalia* spp. do not attack the leaves but cause their wilting and death indirectly by affecting the roots and trunk below.

RELATION BETWEEN PRIMARY AND SECONDARY SYMPTOMS

Fawcett and Klotz (*21*) state that "as high as 90 per cent of the roots may be dead on some palms that are badly affected with decline." In order to investigate further the relation between the primary and secondary symptoms of omphalia root rot, 4 palms (fig. 11) in garden *K* were selected, which stood consecutively in a straight line at intervals of about 40 feet. At one end of the line was a severely diseased palm (no. 16); the next palm (no. 17) showed slight secondary symptoms; the third and fourth palms (nos. 18 and 19) were not visibly affected. Root specimens were taken from the northwest side of each palm (and also from the southeast side of palm no. 17). A rectangular block of soil 12 inches wide, 18 inches long, and 48 inches deep, was excavated at a distance of 24 inches from the trunk of each palm. All segments of primary roots in these blocks of soil were examined, and the percentage of dead roots was calculated (table 1).

A positive correlation was found between the percentage of dead roots and the secondary symptoms of the disease. The severely affected palm (no. 16, table 1) had 41.4 per cent dead roots, whereas the 2 healthy-appearing palms (nos. 18 and 19) had only 1.7 and 3.6 per cent dead roots, respectively. Two samples of roots taken from the palm with slight secondary symptoms (no. 17) yielded 25.7 and 28.7 per cent dead roots, respectively. Fungus cultures made from the root samples indicated that the diseased palms (nos. 16 and 17) were badly affected with *Omphalia tralucida* but that the healthy-appearing palms had not been attacked by this fungus. Since small percentages of dead roots have been observed on several other healthy palms, the presence of such roots on the healthy palms in this experiment was to be expected. It should not be concluded, therefore, that all the dead roots on the 2 diseased palms had been killed by *O. tralucida.*

Death resulting from omphalia root rot is not common. The only authentic cases on record are those involving seedling palms less than two years of age. Failure to establish recently cut offshoots of the Deglet Noor variety in one



Fig. 11.—Four Deglet Noor palms which stood concentrically in a straight diagonal line across the margin of an omphalia-root-rot area: *A*, palm with marked secondary symptoms; *B*, palm with first visible symptoms of decline; *C*, healthy-appearing palm standing next to a diseased palm; *D*, a healthy palm. All photographs were taken at a uniform distance to indicate differences in size.

garden was attributed to the omphalia root rot, after it was discovered that the bases of some of the palms were badly infected with *Omphalia tralucida*. Two isolated cases of large palms of Deglet Noor variety that died suddenly are on record. Dissection revealed large quantities of *O. pigmentata* in the roots of one palm; *O. tralucida* was obtained from roots of the other. Although both of these trees were affected with omphalia root rot, other factors probably contributed to their death. *O. tralucida* was found in a Deglet Noor date palm which had been struck by lightning and also in another palm which died suddenly with the symptoms of rhizosis (*8, 12*).

TABLE 1

DEAD PRIMARY ROOTS ON FOUR DEGLET NOOR DATE PALMS IN GARDEN *K*, IN RELATION TO SECONDARY SYMPTOMS* OF OMPHALIA ROOT ROT

Tree no.	Total primary roots examined†	Primary roots dead	Percentage primary roots dead	Secondary symptoms*
	number	*number*	*per cent*	
16	244	101	41.4	Severe
17	230	59	25.7	Slight
	87	25	28.7	
18	120	2	1.7	None
19	140	5	3.6	None

* See "Secondary Symptoms," p. 20; also, figure 11.

† Root specimens were taken from a rectangular block of soil on the northwest side of each palm and also from the southeast side of palm no. 17. These blocks, 12 inches wide, 18 inches long, and 48 inches deep, were excavated at a distance of 24 inches from the trunk of each tree.

ETIOLOGY

The discussion thus far has been based on the premise that omphalia root rot is caused by *Omphalia pigmentata* and *O. tralucida*.

Klotz (*36*) in 1930 made some preliminary observations of what was then known as "decline disease" and suggested that it was caused either by fungus infection or faulty nutrition.

Haas (*26*) also in 1930 found that the pinnae of diseased date palms contain lower percentages of total nitrogen and potassium in the dry matter but higher percentages of calcium than those of healthy palms. He raised the question whether these differences constitute the cause of decline disease or its effect.

Haas and Klotz (*29*, p. 512) noted that many of the roots of certain diseased palms had deteriorated while the roots of near-by citrus trees were healthy. They noted, also, that citrus interplants in decline-disease areas "thrived while the palms continued to retrograde." They suggested that citrus was not a useful indicator plant because the nutrient requirements and rooting habit of citrus differ widely from those of date palms. These writers found it difficult to defend the view that decline disease was the result of inadequate fertilization. They described in detail how liberal amounts of commercial and animal fertilizers and of organic matter from covercrops were applied to a garden of Deglet Noor palms affected with decline disease. Notwithstanding these treatments, some palms in the better portions of the garden developed symptoms of disease, whereas the palms that were already diseased became steadily worse.

A marked improvement was reported in the case of one badly diseased palm, however, after the application of 50 pounds of copper sulfate to the soil about the base.

Fawcett and Klotz (*21*, p. 12) expressed the belief that the cause of decline disease was in some way related "to the nature of the soil." Many dead roots were found by these workers on badly affected palms, but no characteristic lesions were identified.

At this stage in the investigation the disease was recognized by symptoms of a general nature, such as retarded growth rate, poor quality of fruit, and decayed roots. Theories advanced to account for these symptoms included: first, a possible deficiency of essential food elements; second, toxic substances in the soil; and third, root pathogens. As experience increased, the investigation became centered about two theories: the first, that decline disease was due to faulty nutrition; and the second, that it was caused by pathogenic fungi. To test the first theory, affected palms in the field were treated with various chemicals, and seedling date palms were grown in soil taken from diseased and healthy areas. To test the second, microörganisms were isolated from the roots of diseased palms, and healthy palms were inoculated with pure cultures of the organisms obtained.

NUTRITIONAL STUDIES

Various chemicals were applied[7] in liberal amounts to diseased palms in 5 different date gardens. (Some of the first treatments of this kind were mentioned by Haas and Klotz [*29*]). Injecting tree trunks with weak solutions of copper sulfate, magnesium nitrate, boric acid, and of potassium chloride, in a few preliminary tests, failed to improve the condition of the palms. When dry crystals of copper sulfate were inserted through auger holes into the trunk, localized injury was produced. An attempt to apply copper to the palm by pouring 3 gallons of 4–4–50 bordeaux mixture about the bases of the youngest leaves produced no visible effect.

The principal method employed in the chemical treatment of diseased palms was that of scattering the material on the soil at the base of the palm and carrying it to the roots by means of basin irrigation. Table 2 summarizes the effects of 29 chemical soil treatments on the condition of diseased Deglet Noor date palms in 5 different gardens (*V*, *G*, *Q*, *R*, and *T*). From 1 to 4 applications of each of the chemicals were made between September, 1930, and May, 1933. The total amount of each chemical applied per palm is indicated (table 2). Results are based on the relative recovery of individual palms after the treatment, as observed and recorded by the writer at yearly intervals, from 1931 to 1937.

In an interpretation of the results obtained from these chemical treatments, certain facts regarding the experiment should be borne in mind: (1) The experiment dealt with a comparatively large number of trees and varied conditions; (2) liberal amounts of chemical were applied; (3) many chemicals were tested; (4) surveys were made at regular intervals by the same observer; and (5) the six-year period over which records were taken was probably long enough for any macroscopic effects of the chemical treatments to become evident. Certain criticisms of the experiment are these: (1) The palms were not uniformly affected with disease at the time of treatment and therefore could

[7] Coöperative experiments conducted by the Division of Plant Pathology and the Division of Plant Physiology, University of California Citrus Experiment Station, Riverside.

not be expected to react in the same manner; (2) the method used in recording these data was not highly accurate because only the secondary symptoms of the disease were noted; and (3) an insufficient number of untreated palms was reserved for controls in certain gardens.

While the condition of untreated palms in experimental gardens *V*, *G*, *Q*, and *T* remained unchanged or became worse, that of certain untreated palms in garden *R* improved. The relative recovery of some of the treated palms in garden *R* cannot, therefore, be attributed entirely to the effect of the treatments. This reservation is further substantiated by the fact that identical treatments were made in gardens *R* and *T*; yet very little improvement was noted in the latter.

The condition of the treated palms was, in general, similar to that of the controls. Although Haas and Klotz (*29*), in one of their studies, reported the beneficial effect of copper sulfate on a diseased palm, its effect on 94 other palms in the present studies does not indicate that copper sulfate is beneficial for the treatment of omphalia root rot. Large additions of nitrogen, potassium, phosphorus, and iron to the soil failed to produce any marked change in the condition of diseased palms. The application of at least 17 different chemical elements in the "A–Z" treatment (see table 2, footnote §) produced no visible effect. Copper sulfate, aluminum sulfate, borax, boric acid, ferrous sulfate, Semesan (hydroxymercurichlorophenol), sulfur, and dry lime-sulfur are known to have certain fungicidal properties, but when applied to the soil in these experiments, they did not control the disease. Zinc sulfate, a compound which is used on citrus both for its nutritive and for its fungicidal properties, produced some improvement in the condition of 2 out of 4 diseased palms. The evaluation of the zinc sulfate treatment must await further evidence.

In summarizing these experiments, it is apparent that very little, if any, information was obtained which would indicate the cause of or the remedy for omphalia root rot. These results, though negative in character, indicate both the tolerance of the date palm to relatively high concentrations of different chemical elements and the inability of mature diseased palms to benefit from generous applications of plant nutrients. The results of these experiments do not preclude the possibility that other chemical soil treatments might be beneficial, but they indicate some of the difficulties that may be encountered.

In order to study the fertility of different soils in relation to the growth of date palms, 23 samples of air-dried soil[8] from healthy and diseased areas were used in a pot experiment in the greenhouse. Seedlings of the Deglet Noor variety were grown for one year in these different lots of soil and were then measured for the amount of growth. These data (table 3) indicate no significant differences in average length of longest leaf and average diameter of basal node between seedlings grown in soil from healthy areas and those grown in soil from diseased areas. More growth was produced in soil from the first-foot level than from the fifth foot. The top soil from both healthy and diseased areas in experimental gardens *Q* and *V* (fig. 1) produced growth that was equal to or better than that obtained in a fine-sandy-loam potting soil obtained at Riverside. No symptoms of omphalia root rot appeared in any of the palms in this experiment.

[8] Collected in March, 1931, by A. R. C. Haas and L. J. Klotz.

TABLE 2

EFFECT OF DIFFERENT CHEMICAL SOIL TREATMENTS* ON THE CONDITION OF DISEASED DEGLET NOOR DATE PALMS, 1930–1937†

Treatment no., chemical, and amount applied per palm	Relative condition of palms after treatment														
	Experimental garden *V*‡			Experimental garden *G*‡			Experimental garden *Q*‡			Experimental garden *R*‡			Experimental garden *T*‡		
	Worse	Unchanged	Improved	Worse	Unchanged	Improved	Worse	Unchanged	Improved	Worse	Unchanged	Improved	Worse	Unchanged	Improved
	number	*number*	*number*	*number*	*number*	*number*	*number*	*number*	*number*	*number*	*number*	*number*	*number*	*number*	*number*
1. None (control)	0	2	0	1	3	0	2	4	0	0	23	21	1	6	0
2. Aluminum sulfate															
100 pounds	..	..	..	..	..	..	0	1	0	..	..	..	..	..	..
250 pounds	..	..	..	..	..	..	..	..	..	0	2	0	0	2	0
3. Borax, 4 pounds	..	..	..	..	..	..	..	..	..	0	2	0	1	1	0
4. Calcium nitrate															
100 pounds	..	..	..	..	..	..	0	1	0	..	..	..	..	..	..
150 pounds	..	..	..	..	..	..	0	1	0	..	..	..	..	..	..
225 pounds	0	2	0	..	..	..	..	..	..	..	..	..	..	..	..
300 pounds	..	..	..	0	3	0	..	..	..	..	..	..	..	..	..
5. Copper sulfate															
25 pounds	..	..	..	..	..	..	1	7	1	..	..	..	..	..	..
50 pounds	..	..	..	..	..	..	9	14	0	..	..	..	..	..	..
75 pounds	1	3	0	..	..	..	2	5	0	..	..	..	0	1	0
100 pounds	..	..	..	1	2	1	0	2	0	..	..	..	0	1	0
125 pounds	..	..	..	1	2	0	..	..	..	..	..	..	..	..	..
150 pounds	0	4	0	0	3	0	..	..	..	0	1	2	0	3	0
225 pounds	0	2	0	..	..	..	..	..	..	..	..	..	..	..	..
6. Ferrous sulfate															
75 pounds	..	..	..	0	3	0	..	..	..	..	..	..	..	..	..
100 pounds	..	..	..	1	5	0	..	..	..	..	..	..	..	..	..
225 pounds	..	..	..	0	2	0	..	..	..	..	..	..	..	..	..
250 pounds	..	..	..	..	..	..	0	1	1	..	..	..	..	..	..
600 pounds	..	..	..	0	2	0	..	..	..	..	..	..	..	..	..
7. Potassium chloride															
150 pounds	2	0	0	..	..	..	..	..	..	..	..	..	..	..	..
200 pounds	..	..	..	2	1	0	..	..	..	0	2	1	0	3	0
225 pounds	0	2	0	..	..	..	..	..	..	..	..	..	..	..	..

8. Potassium nitrate																
50 pounds	..	..	..	..	..	..	0	1	0							
100 pounds	..	..	..	..	..	..	0	3	0							
200 pounds	..	..	..	..	..	..	..	..	..	0	1	1	0	2	0	
225 pounds	1	1	0	..	..	..	..	..	..	..	..	..	..	..	..	
300 pounds	..	..	..	1	2	0	..	..	..	..	..	..	..	..	..	
9. Potassium sulfate																
75 pounds	1	1	0	..	..	..	..	..	..	..	..	..	..	..	..	
100 pounds	..	..	..	..	..	..	0	2	0	..	..	..	..	..	..	
200 pounds	..	..	..	..	..	..	..	..	..	0	2	0	0	2	0	
225 pounds	2	0	0	..	..	..	..	..	..	..	..	..	..	..	..	
300 pounds	..	..	..	1	1	0	..	..	..	..	..	..	..	..	..	
10. Semesan (hydroxymercurichlorophenol), 1 pound	..	..	..	..	..	..	0	1	0	..	..	..	..	..	..	
11. Slaked lime, 100 pounds	..	..	..	..	..	..	1	0	0	..	..	..	..	..	..	
12. Sodium chloride																
100 pounds	..	..	..	..	..	..	0	1	0	..	..	..	..	..	..	
150 pounds	2	0	0	..	..	..	0	1	0	..	..	..	..	..	..	
200 pounds	..	..	..	..	..	..	..	..	..	0	3	0	0	3	0	
300 pounds	..	..	..	0	2	1	..	..	..	..	..	..	..	..	..	
13. Sodium nitrate, 200 pounds	..	..	..	..	..	..	..	..	..	0	0	2	0	2	0	
14. Sulfur																
100 pounds	..	..	..	..	..	..	1	1	0	..	..	..	..	..	..	
150 pounds	..	..	..	0	2	0	..	..	..	..	..	..	..	..	..	
200 pounds	..	..	..	..	..	..	..	..	..	0	1	1	0	2	0	
15. Triple superphosphate																
100 pounds	..	..	..	..	..	..	2	3	0	..	..	..	..	..	..	
150 pounds	2	0	0	..	..	..	..	..	..	..	..	..	..	..	..	
300 pounds	..	..	..	0	3	0	..	..	..	..	..	..	..	..	..	
16. Zinc sulfate, 100 pounds	..	..	..	..	..	..	..	..	..	0	1	1	0	1	1	
17. "A–Z"§	..	..	..	..	..	..	..	..	..	0	2	0	0	1	0	
18. Copper sulfate, 50 pounds, and boric acid, 5 pounds	..	..	..	..	..	..	1	0	0	..	..	..	..	..	..	
19. Copper sulfate, 50 pounds, and ferrous sulfate, 25 pounds	..	..	..	..	..	..	0	4	0	..	..	..	..	..	..	

* Applications of chemicals (from one to four applications to each palm) were made between September, 1930, and May, 1933.
† Two hundred and forty-six palms were included in this test. Results were observed at yearly intervals, from 1931 to 1937, inclusive.
‡ See figure 1 for key to experimental gardens.
§ This treatment included boric acid, potassium iodide, titanium sulfate (and chloride), potassium bromide, strontium nitrate, lithium nitrate, manganese sulfate (and chloride), ammonium sulfate, copper sulfate, zinc sulfate, aluminum sulfate, and ferrous sulfate.

(*Table 2 concluded on p. 34*)

TABLE 2 (*Concluded*)

Treatment no., chemical, and amount applied per palm	Relative condition of palms after treatment														
	Experimental garden V‡			Experimental garden G‡			Experimental garden Q‡			Experimental garden R‡			Experimental garden T‡		
	Worse	Unchanged	Improved	Worse	Unchanged	Improved	Worse	Unchanged	Improved	Worse	Unchanged	Improved	Worse	Unchanged	Improved
	number	*number*	*number*	*number*	*number*	*number*	*number*	*number*	*number*	*number*	*number*	*number*	*number*	*number*	*number*
20. Copper sulfate, 50 pounds, and manganese sulfate, 5 pounds	..	..	..	..	..	..	1	0	0	..	..	..	..	..	.
21. Copper sulfate, 50 pounds, and potassium chloride, 25 pounds	..	..	..	..	..	..	2	4	0	..	..	..	..	..	..
22. Copper sulfate, 100 pounds, and potassium nitrate, 100 pounds	..	..	..	..	..	..	0	1	0	..	..	..	..	..	..
23. Copper sulfate, 50 pounds, and sodium chloride, 25 pounds	..	..	..	..	..	..	3	1	0	..	..	..	..	..	..
24. Copper sulfate, 100 pounds, and triple superphosphate, 100 pounds	..	..	..	..	..	..	0	1	0	..	..	..	..	..	..
25. Copper sulfate, 50 pounds, and zinc nitrate, 20 pounds	..	..	..	..	..	..	1	0	0	..	..	..	..	..	..
26. Copper sulfate, 100 pounds, potassium nitrate, 100 pounds, and triple superphosphate, 100 pounds	..	..	..	..	..	..	1	1	0	..	..	..	..	..	..
27. Copper sulfate, 100 pounds, ferrous sulfate, 100 pounds, potassium nitrate, 100 pounds, and triple superphosphate, 100 pounds	..	..	..	..	..	..	..	..	..	0	1	1	0	2	0
28. Dry lime-sulfur, 100 pounds	..	..	..	..	..	..	0	1	0	..	..	..	..	..	..
29. Potassium nitrate, 100 pounds, and triple superphosphate, 100 pounds	..	..	..	..	..	..	0	1	0	..	..	..	..	..	..

* Applications of chemicals (from one to four applications to each palm) were made between September, 1930, and May, 1933.
† Two hundred and forty-six palms were included in this test. Results were observed at yearly intervals, from 1931 to 1937, inclusive.
‡ See figure 1 for key to experimental gardens.
§ This treatment included boric acid, potassium iodide, titanium sulfate (and chloride), potassium bromide, strontium nitrate, lithium nitrate, manganese sulfate (and chloride), ammonium sulfate, copper sulfate, zinc sulfate, aluminum sulfate, and ferrous sulfate.

TABLE 3

RELATIVE GROWTH OF SEEDLING DATE PALMS* IN SOILS FROM DISEASED AND HEALTHY AREAS

Experimental garden,† condition of soil, and soil depth	Texture of soil	Plants	Average length of longest leaf	Average diameter of basal node
		number	*cm*	*mm*
Garden *Q* (Coachella)				
Healthy area				
First foot	Fine sandy loam	6	44	12
Second foot	Sandy loam	5	42	10
Third foot	Clay loam	3	39	9
Fourth foot	Loam	6	35	8
Fifth foot	Clay loam	3	33	11
Diseased area				
First foot	Fine sandy loam	5	51	10
Second foot	Clay loam	6	41	9
Third foot	Clay loam	5	38	10
Fourth foot	Fine sandy loam	4	35	9
Fifth foot	Fine sandy loam	4	37	10
Garden *V* (Oasis)				
Healthy area				
First foot	Sandy loam	4	47	14
Second foot	Sandy loam	3	39	9
Third foot	Sandy loam	6	31	8
Fourth foot	Sandy loam	5	23	7
Fifth foot	Light sandy loam	6	30	6
Diseased area				
First foot	Fine sandy loam	5	45	11
Second foot	Sandy loam	5	36	12
Fourth foot	Light sandy loam	5	33	10
Garden *G* (Indio)				
Healthy area				
Fourth foot	Loam	2	34	9
Garden *B* (Indio)				
Healthy area				
Third foot	Light sandy loam	5	33	10
Fifth foot	Fine sand	3	34	9
Riverside				
Healthy area				
Potting soil	Fine sandy loam	6	34	9
Potting soil	Fine sandy loam	6	34	11

* Seedlings of Deglet Noor variety grown for one year in earthen pots in the greenhouse.
† See figure 1 for key to experimental gardens.

EXPERIMENTS WITH PATHOGENIC FUNGI

While nutritional studies were under way, work was initiated to test the theory that the disease is caused by pathogenic fungi. Although Fawcett and Klotz (*21*) observed a high percentage of dead roots on palms affected with decline, they described no characteristic lesions of the disease. In 1930 Klotz isolated a white fungus[9] from the upper roots of a Deglet Noor palm which

[9] Klotz states that "no attempt was made to induce the fungus to produce fruiting bodies or further to test its pathogenicity." Note from L. J. Klotz, September 25, 1942. A previous statement (*10*) that Klotz obtained slight evidences of infection from the inoculation of seedling date palms was based on a misunderstanding; the experiments mentioned actually dealt with *Thielaviopsis paradoxa* (De Seynes) v. Höhn, and not with *Omphalia*.

had died suddenly. A culture of this fungus (identified later as *Omphalia pigmentata* Bliss) was given to the writer, who took up date-disease investigations about that time.

In 1931 the writer began a series of critical examinations of the roots and trunks of diseased and of healthy-appearing date palms. Many specimens were cultured and a wide variety of fungi and bacteria were isolated. At first, all

TABLE 4

PATHOGENICITY* OF FUNGI CULTURED FROM ROOTS AND TRUNKS OF DISEASED DATE PALMS IN THE COACHELLA VALLEY, 1929–1942

Fungi	Sources	Pure cultures	Inoculation experiments	Pathogenicity of cultures
	number	*number*	*number*	
Ascochyta sp.	2	2	2	Negative
Aspergillus niger van Tiegh.	2	2	2	Negative
Cephalosporium spp.	4	4	4	Negative
Ceratostomella radicicola Bliss	4	8	13	Positive
Diplodia phoenicum (Sacc.) Fawcett and Klotz	3	5	4	Negative
Flammula earlei Murr.	1	2	2	Negative
Fusarium spp.	5	11	11	Negative
Helminthosporium sp.	2	2	1	Negative
Mucor sp.	1	1	1	Negative
Omphalia pigmentata Bliss and *Omphalia tralucida* Bliss†	23	77	150	Positive
Penicillium spp.	3	3	2	Negative
Phomopsis phoenicicola Trav. and Spessa	4	5	5	Negative
Polyporus sp.	1	1	1	Negative
Poria sp.	1	1	1	Negative
Pythium (?) spp.	3	7	8	Negative
Rhizoctonia sp.	6	7	5	Negative
Rhizoctonia bataticola (Taub.) Butler	3	3	2	Negative
Thielaviopsis paradoxa (De Seynes) v. Höhn.	1	1	1	Positive
Trichoderma lignorum (Tode) Harz	4	5	5	Negative
Verticillium sp.	1	1	1	Negative
Unidentified:				
a) Sterile mycelium with clamp connections	5	5	5	Negative
b) Miscellaneous	9	15	14	Negative

* Tested by means of artificial soil inoculations on potted seedlings of Deglet Noor date palm.
† See table 5 for source and pathogenicity of these fungi.

the organisms taken from diseased palms were tested for pathogenicity, but later the field of investigation was narrowed to a few species of fungi.

Experiments on the pathogenicity of fungi isolated from roots and trunks of diseased palms (table 4) were conducted in the greenhouse. Seedlings of the Deglet Noor variety were grown in nonsterile fine sandy loam in 5-gallon tin containers. Usually 9 seedlings were in each container, and inoculations were made when the palms were from 3 to 12 months of age. Pure cultures of the fungi to be tested were first grown on Pillsbury's bran in Erlenmeyer flasks. To inoculate the seedling palms, the upper 1-inch layer of soil was removed from the container, and granules of the fungus-covered bran (80 ml per 5-gallon container) were spread over the soil and about each plant; the topsoil was then returned. All of these experiments included controls in which sterile bran was used as inoculum. Some of the palms were wounded artificially in these preliminary experiments, though many other inoculations were made

without intentional injury to the plants. The inoculated palms were grown for a period of 6 to 12 months at a temperature of 27° C. or above. They were then removed from the soil and examined for the presence of disease lesions. Reisolation of fungi from necrotic lesions, comparison of the isolates with the



Fig. 12.—Seedling date palms showing primary symptoms of omphalia root rot: *A*, two Iteema seedlings (with seeds attached) and a Deglet Noor seedling taken 67 days after inoculation; *B*, healthy basal node and roots of a noninoculated seedling (control); *C* and *D*, diseased seedlings inoculated with cultures B–207 and B–267, respectively. Basidiospores from culture B–207 produced culture B–267. Both cultures were highly pathogenic on Deglet Noor seedlings.

original cultures, and, in some cases, reinoculations into other experimental plants, were steps taken in accordance with Koch's rules of proof.

Of the many species of fungi tested for pathogenicity on potted seedling

date palms (table 4), only 4 caused necrotic lesions. The *Chalaropsis* stage of *Ceratostomella radicicola* Bliss and *Thielaviopsis paradoxa* (De Seynes) v. Höhn. were pathogenic when introduced through wounds in the experimental plants. The symptoms produced by these two fungi were not commonly asso-

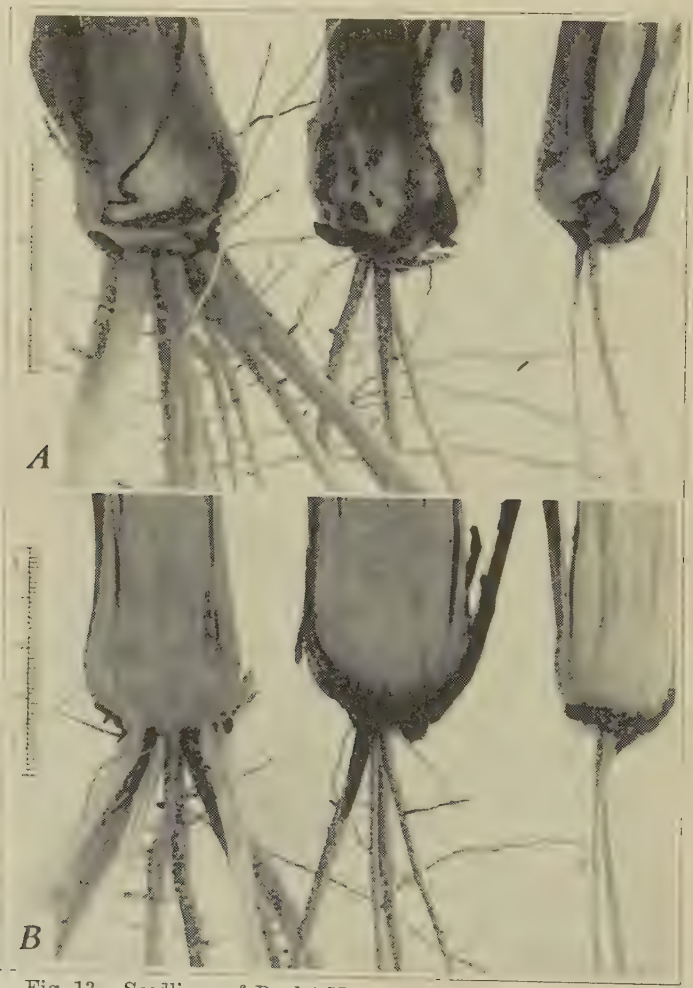


Fig. 13.—Seedlings of Deglet Noor date palm, showing the abortion of primary roots due to *Omphalia tralucida: A*, noninoculated control plant (left) and two inoculated plants; *B*, same seedlings as in *A* but cut longitudinally to show the necrotic lesions in the roots and in the base of the trunk.

ciated with the decline disease, however, and for that reason neither fungus was considered seriously as the primary cause. Numerous cultures of sterile white fungi with clamp connections were isolated from roots of diseased palms. These fungi, which were later (1938) described (*10*) as two new species of *Omphalia* (*O. pigmentata* Bliss and *O. tralucida* Bliss), were constantly associated with the decline disease, and on experimental plants they produced

symptoms similar to those observed on naturally infected palms in the field. These species were highly pathogenic, both on wounded and on unwounded plants, and caused death or severe stunting in potted date-palm seedlings (figs. 12 and 13).

Evidence of the pathogenic nature of *Omphalia* spp. was so clearly marked, even in the preliminary inoculation experiments, that further investigations on the cause of the disease were focused on these fungi. The source and pathogenicity of the various strains of *Omphalia* spp. (table 5) cultured from date palms during a period of twelve years (1930–1942), constitute some of the basic findings in this study. Of the many palms examined, a large proportion of those having secondary symptoms of the disease yielded cultures of *Omphalia* spp. These fungi were most evident in palms showing early symptoms of disease. The detection of omphalia was usually more difficult in palms which had been affected for several years. In such cases the necrotic roots yielded various nonpathogenic organisms that had apparently invaded the tissues originally affected by omphalia.

To examine a palm for the presence of omphalia, roots were usually taken from a narrow pit dug at a distance of 1 or 2 feet from the trunk. The danger of causing unreasonable injury to the palm limited the amount of digging and also the number of root segments examined. Whereas positive evidence of the presence of omphalia in a palm was obtained by culturing the fungus, negative results from isolation experiments did not necessarily prove the absence of the pathogen. Mechanical injury and the adherence of soil to the root specimens increased the difficulty of culturing the fungus, and sometimes it was impossible to isolate omphalia from contaminating organisms.

At the conclusion of the present experiments, *Omphalia pigmentata* had been isolated from palms in 8 gardens (table 5), and *O. tralucida* from palms in 20 gardens. Both species have been detected in 5 of the 23 affected gardens, though under natural conditions both have never been obtained from the same palm. The pathogens have been cultured from palms of the Khadrawy, Zahidi, Saidy, Tafazwin, Horra, and Iteema varieties and from certain seedling date palms, but most of the isolates have originated from palms of the Deglet Noor variety. Fourteen isolates of *O. pigmentata* and 62 isolates of *O. tralucida* were obtained and all were pathogenic on potted seedlings of date palm. Of the 150 inoculation experiments summarized in table 5, only 7 were negative. No evidence of omphalia was found in any of the controls.

In other experiments, inoculations were made on seedlings of other varieties of date palm and on larger date palms growing in the field. Potted seedlings of 6 varieties[10] were inoculated with *Omphalia pigmentata* and *O. tralucida* at 4 months of age (table 6). Nine months later, when the seedlings were removed from the soil, infection was found in all lots of inoculated palms. Although *O. pigmentata* appeared more virulent than *O. tralucida* in this experiment, the relative pathogenicity of these fungi was considered equal on seedlings of all 6 varieties.

Three-year-old seedling date palms in the field at the University of California Citrus Experiment Station were inoculated in various ways. A primary root of one was excavated together with a number of its lateral branches. The

[10] Seeds were obtained from R. W. Nixon, United States Date Garden, Indio, California.

TABLE 5

PATHOGENICITY OF *Omphalia* SPP. CULTURED FROM DATE PALMS, 1930–1942

Culture, source, and no.	Pathogenicity experiments*		Reisolated culture no.	Culture, source, and no.	Pathogenicity experiments*		Reisolated culture no.
	Number positive	Number negative			Number positive	Number negative	
Omphalia pigmentata							
Garden *D*				Garden *K*			
Deglet Noor				Deglet Noor			
1803†	10	0	B-76‡ B-78‡	B-627	1	0	
B-144	2	0	B-268‡	Garden *Q*			
				Zahidi			
				B-562	1	0	
Garden *F*				Garden *T*			
Deglet Noor				Deglet Noor			
B-464	2	0		B-152	10	0	B-216
Garden *G*				B-229	1	0	
Deglet Noor				B-525	1	0	
B-182	3	0	B-224	Zahidi			
B-200	1	0	B-286	B-526	1	0	
B-201	1	0	B-290				
				Citrus Experiment			
Garden *I*				Station, Riverside			
Khadrawy				Saidy			
B-622	1	0		B-376	5	1	
Omphalia tralucida							
Garden *A*				Garden *I*			
Deglet Noor				Khadrawy			
B-184	1	2	B-262	B-668	1	0	
B-186	1	0		B-670	1	0	
B-597	1	0					
				Garden *J*			
Garden *B*				Deglet Noor			
Deglet Noor				B-333	1	0	B-412
B-318	1	2	B-410				
B-320	1	0	B-411	Garden *K*			
B-353	1	0		Deglet Noor			
Deglet Noor seedling				B-611	1	0	
B-352	1	0		B-619	1	0	
				B-620	1	0	
Garden *C*				B-621	1	0	
Deglet Noor							
B-196	1	0	B-280	Garden *L*			
B-672	1	0		Deglet Noor			
				B-269	1	0	B-304
Garden *E*				B-594	1	0	
Deglet Noor							
B-572	2	0		Garden *M*			
				Deglet Noor			
Garden *G*				B-206	1	0	B-289
Deglet Noor							
B-628	1	0					

TABLE 5 (*Continued*)

Culture, source, and no.	Pathogenicity experiments*		Reisolated culture no.
	Number positive	Number negative	
Omphalia tralucida—(*Continued*)			
Garden *N*			
Deglet Noor			
B-207	3	0	B-267‡
B-209	1	0	B-283
B 349	1	0	
B-370	1	0	
B-371	1	0	
B 372	1	0	
B-373	1	0	
B-435	1	0	
B-437	1	0	
B-438	1	0	
Seedling male			
B-522	1	0	
Seedling male			
B 523	1	0	
Garden *O*			
Deglet Noor			
B 596	1	0	
Garden *Q*			
Deglet Noor			
B-33	9	2	B-79‡
B 39	4	0	B-75‡
B-173	1	0	B-221
B-174	1	0	B-222
B-181	25	0	B-223
B-345	1	0	
B-346	1	0	
B 347	1	0	
B 348	1	0	
B-527	1	0	
B-610	1	0	
Garden *S*			
Deglet Noor			
B-616	1	0	
Garden *T*			
Deglet Noor			
B-581	1	0	
B-582	1	0	
B-624	1	0	
Khadrawy			
B-623	1	0	
B-625	1	0	
B-626	1	0	
Tafazwin			
B-524	1	0	
Garden *U*			
Deglet Noor			
B-618	1	0	
Garden *V*			
Deglet Noor			
B 244	3	0	B-281
B-245	2	0	B-271‡
B-579	1	0	
B-580	1	0	
Horra			
B-530	1	0	
Iteema			
B-529	1	0	
Garden *W*			
Deglet Noor			
B-617	1	0	
Garden *Y*§			
Deglet Noor			
B-630	1	0	
Garden *Z*			
Deglet Noor			
B-698	0	0	

* Pathogenicity tested on seedlings of Deglet Noor date palm, 3 to 12 months of age. Each inoculation experiment included 5 to 10 plants growing in soil in a 5-gallon container.
† Isolated by L. J. Klotz, December 17, 1930.
‡ Culture found to be pathogenic in other experiments.
§ Located near Garnet, California.

tips of these laterals were inserted in test tubes containing pure cultures of *Omphalia tralucida* on agar. The soil was returned to its place. Five months later the inoculated root showed several large necrotic lesions. There were also rhizomorphs on the surface of the root (plate 4, *B*).

Other seedlings in the same row were inoculated by temporarily removing

the topsoil on one side and inserting, below the basal node, pure cultures of omphalia on bran. In some plants inoculation was through wounds purposely made about the bases of older leaves; other plants were inoculated without intentional wounding. Thirteen months after inoculation several new primary roots had developed on each of the control plants, but few, or none, had developed on the inoculated plants (fig. 14). Here, as with the potted seedlings, omphalia had caused abortion of young primary roots and necrotic, local

TABLE 6

RELATIVE VIRULENCE OF *Omphalia* SPP. ON POTTED SEEDLINGS OF SIX VARIETIES OF DATE PALMS*

Female parentage of palms and inoculum	Total plants	Plants attacked
	number	*number*
Deglet Noor		
Control	7	0
O. pigmentata	8	8
O. tralucida	7	2
Halawy		
Control	10	0
O. pigmentata	9	8
Khadrawy		
Control	2	0
O. pigmentata	9	9
Khalasa		
O. pigmentata	4	4
Tazizaoot		
Control	8	0
O. pigmentata	10	10
O. tralucida	8	3
Zahidi		
Control	8	0
O. pigmentata	9	9
O. tralucida	7	2

* Seedlings inoculated at 4 months of age and taken up 9 months later.

lesions in the older roots (fig. 15). The fiber and leaf bases were affected, but the most serious injury was found in the roots and in the basal region of the trunk. The inoculated palms in this experiment had become somewhat stunted and yellowish in color. The wounded plants had become infected but they were not noticeably poorer than the nonwounded ones. Omphalia was reisolated from necrotic lesions in these plants.

Important evidence of the pathogenicity of *Omphalia* spp. was also obtained on date palms in the Coachella Valley. The first inoculation experiment with rooted offshoots of known variety was begun May 13, 1932, in experimental garden *Q*. Thirteen healthy-appearing offshoots of Deglet Noor, Khustawy, Iteema, and Zahidi varieties, were planted in a row at intervals of 10 feet. The palms were arranged so that the controls, which included all 4 varieties, stood at one end of the row, while a similar group of palms to be inoculated stood at the other end. Between the two groups were guard palms of the Deglet Noor variety.

Six of the palms were inoculated after one year with a pure culture (B–33) of *Omphalia tralucida* which had been taken from one of the diseased palms in

experimental garden *Q*. The inoculation was made by placing 320 ml of fungus-covered bran about the trunk of each palm in a 1-foot zone extending upward from the base of the roots. Care was taken to avoid wounding. The control palms were not disturbed.



Fig. 14.—Three-year-old date seedlings from an inoculation experiment in the field: *A*, noninoculated control plant; *B*, inoculated plant with necrotic lesions of omphalia root rot on roots and leaf base. Note the young, peglike primary roots in *A* and the absence of such roots in *B*.

An Iteema and a Deglet Noor palm died shortly after inoculation because of failure to take root. Another Deglet Noor palm was accidentally broken 12 months after being inoculated. Omphalia was already well established in the base of this palm, though the top showed no secondary symptoms. Brown, necrotic lesions in several roots yielded cultures of *O. tralucida*, and in two places the primary roots had been killed, apparently by this fungus.

The other palms were not disturbed for more than five years from the time of inoculation. During this interval the inoculated palms appeared somewhat smaller and more yellow than their controls.

Omphalia tralucida was reisolated from each of the 3 remaining inoculated palms, which were taken up in 1938. Thirty-two per cent of the roots about the base of the Deglet Noor palm were affected, but in the roots of the Khustawy and Zahidi palms no necrotic lesions could be found. The fungus had apparently persisted as a saprophyte in the dead leaf bases of these palms. The guard palms and all the control palms were free from *O. tralucida,* but one

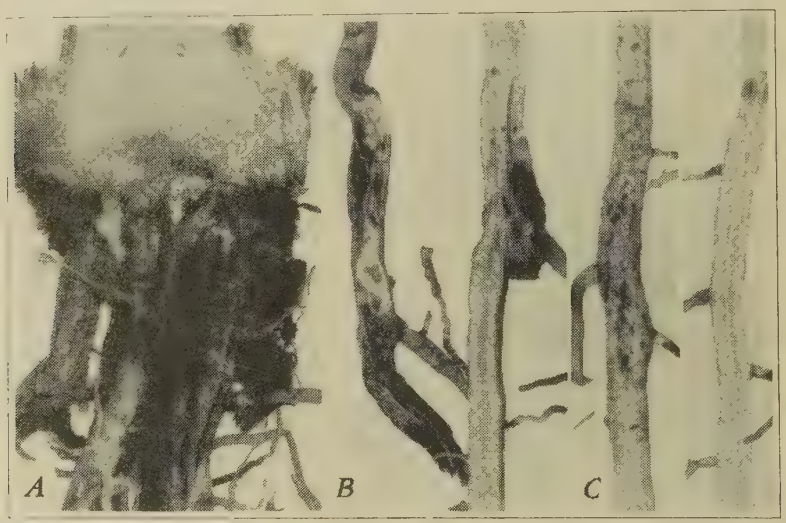


Fig. 15.—Omphalia root rot, induced by artificial inoculation with *Omphalia tralucida*: *A*, longitudinal section through trunk of infected plant; *B*, diseased roots; *C*, healthy roots.

Zahidi showed considerable root necrosis (fig. 16), and yielded cultures of *O. pigmentata.* No explanation can be offered for this discrepancy except the possibility that the palm was already infected when it was selected for the experiment.

Although rather limited in scope, this experiment is of importance because it demonstrated, for the first time, the ability of *Omphalia tralucida* to produce typical root-rot lesions in palms of the Deglet Noor variety in the same environment where the disease had developed naturally. Cultures that were reisolated from root-rot lesions were similar to the original culture, both in appearance and in pathogenicity. Because of these facts Koch's rules of proof were considered satisfied. There was indication also that the Deglet Noor variety is relatively more susceptible to omphalia root rot than the Khustawy and Zahidi varieties.

In order to continue and enlarge the studies on the relative susceptibility of commercial date varieties to the omphalia root rot, palms of 18 varieties were planted in 1934 in a 4-acre experimental garden near Mecca, California (fig.

1, *X*). Although the final results have not been obtained, some of the preliminary findings may be reported.

Disease-free offshoots were purchased from various date growers or were obtained through the courtesy of the United States Department of Agriculture Bureau of Plant Industry. The palms were planted in the usual orchard spacing, the garden being divided into two equal blocks, so that the block at the south side could be inoculated with *Omphalia* spp., while the one at the north side could be held as a control.

Although the soil in the Mecca plot was at first very saline, most of the offshoots became established and grew with a moderate degree of vigor. Heavy

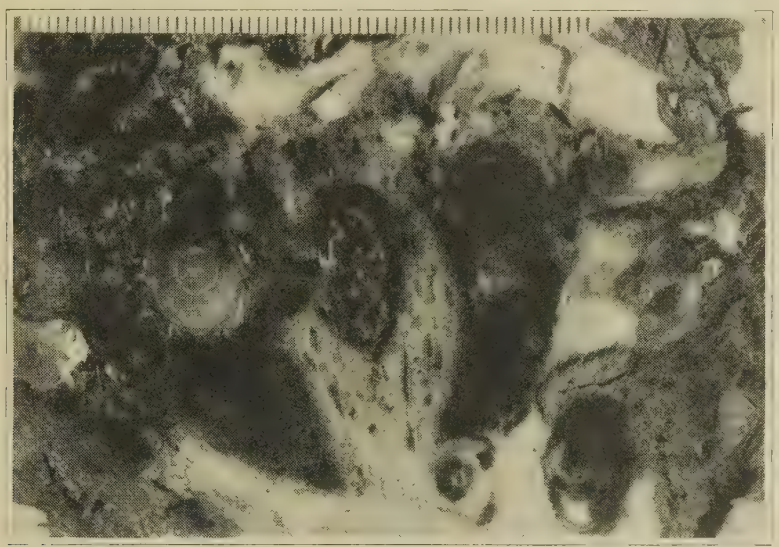


Fig. 16.—Tangential section through the trunk of a naturally infected Zahidi palm, showing necrotic lesions from which *Omphalia pigmentata* was isolated. Graduations in mm.

applications of water in the irrigation basins helped to leach the salts to depths below the principal root zone, and sulfur was used to reduce the pH value of the soil. Straw, with ammonium phosphate, was applied at yearly intervals to improve the physical and nutritional characteristics of the soil.

The experimental palms were well established and appeared to be in a favorable condition of growth in May, 1938, when the inoculations were made. Each palm in the inoculated block received 650 ml of fungus-covered bran about the trunk in the upper part of the root zone. Some roots were cut by the digging tools, but more serious injury was carefully avoided. The inoculum, which was applied to the roots of each palm through two shallow pits, was covered with soil immediately to prevent drying. Palms of all 18 varieties were inoculated with a pure culture (B–181) of *Omphalia tralucida* from garden *Q*. A pure culture (1803) of *O. pigmentata* from garden *D* was used to inoculate other palms of 6 varieties. The palms in the control block were treated in the same manner, except that sterile bran was used for the inoculations.

The roots of representative palms were examined 2 to 3 months after the time of inoculation. In all cases omphalia had remained viable during this period and had produced typical lesions in both wounded and unwounded roots (fig. 17). *Omphalia tralucida* was reisolated from lesions in inoculated palms of the following varieties: Barhee, Dayri, Deglet Noor, Halawy, Hayany, Hellali, Iteema, Khadrawy, Khalasa, Khustawy, Maktoom, Medjool,

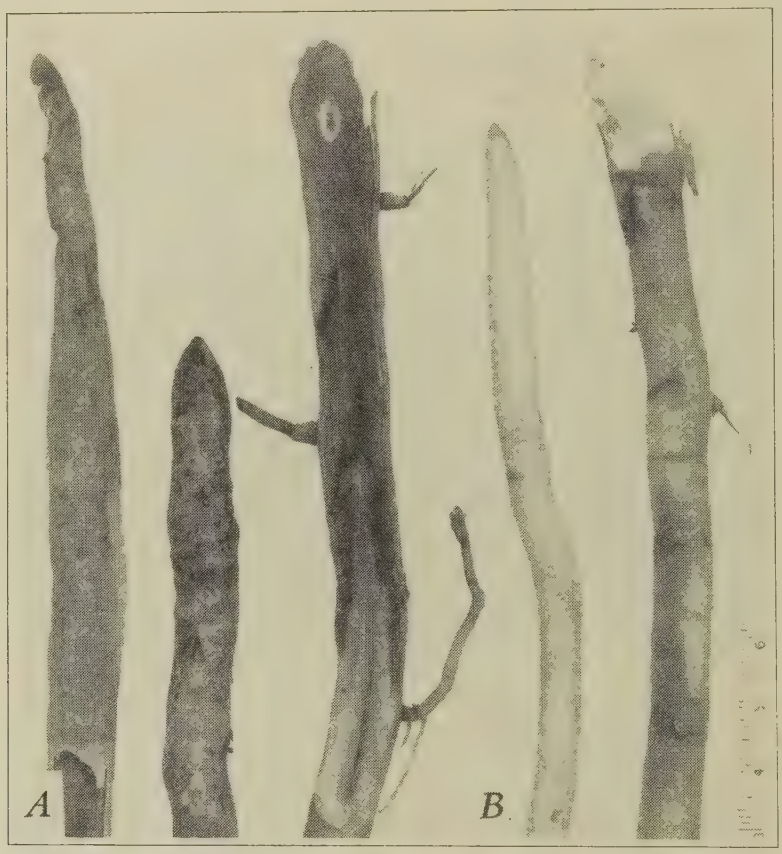


Fig. 17.—Roots from 2 Khadrawy date palms in the artificial-inoculation experiment near Mecca (garden *X*): *A*, inoculated with *Omphalia pigmentata*; *B*, noninoculated control. The photograph was taken 3 months after inoculation. Darkened injuries in one of the control roots were due to wounds that were sustained at the time of inoculation.

Rhars, Saidy, Sayer, Tazizaoot, Thoory, and Zahidi. *O. pigmentata* was recovered from similar lesions in inoculated palms of Deglet Noor, Halawy, Khadrawy, Saidy, Thoory, and Zahidi varieties. There was no evidence of omphalia root rot in specimens from the control block.

Secondary symptoms of omphalia root rot have not appeared in the Mecca plot since inoculation. From other studies referred to later, the secondary symptoms would be expected to require five to seven years for their development. The original inoculum has largely disappeared, but the viable mycelium

of *Omphalia* spp. has recently been found in some palms without difficulty. The preliminary results of this experiment indicate that, under certain conditions, the roots of at least 18 named varieties of date palm are attacked by *O. tralucida* and that the roots of at least 6 of these varieties are attacked by *O. pigmentata.*

The relative pathogenicity of the two species of *Omphalia* is difficult to judge. In experiments with potted seedling palms, *O. tralucida* usually causes more injury than *O. pigmentata.* The opposite has been true in certain cases, however. The effect of inoculation with mixed cultures of the two species has not been more severe than with either one alone. In testing the pathogenicity of newly isolated cultures, a routine procedure now is to inoculate potted seedling date palms. The results are usually evident within a period of 2 months. This method is necessary for a critical diagnosis of the disease. It is relatively quick, inexpensive, and is believed to be very accurate.

THE CAUSAL ORGANISMS

The evidence obtained leads to the conclusion that the decline disease is caused by the fungi, *Omphalia pigmentata* and *O. tralucida.* Attention is therefore directed to a brief description of these two fungi and to a study of their physiology.

During the early years of the investigation, these *Omphalia* spp. were known only in the mycelial stage. Colonies of sterile white mycelium were formed on the common types of nutrient agar, and, when examined microscopically, the hyphae were characterized by clamp connections at the septa (plate 2, *C*). These fungi were cultured by planting bits of infected tissue on slants of Rawlin's corn-meal agar. Incubated at 31° C, the cultures were examined frequently and purified by transferring hyphal tips to slants of glucose potato agar. Without knowledge of their true classification, these cultures were distinguished from other species of fungi by means of microscopic examination and by the inoculation of experimental plants. It was noted, also, that some variations existed in the macroscopic appearance of the colonies. Most conspicuous and constant of these variations was a pigment which formed in certain cultures when they were grown at favorable temperatures on slants of 2 per cent glucose potato agar. The other cultures failed to produce this pigment when grown under similar conditions.

It was supposed that these fungi were basidiomycetous, but it was not until 1934 that the sporophores were first recognized. Small sporophores (plates 2, 3) developed in the greenhouse from dead leaf bases of artificially inoculated date-palm seedlings. Later it was found that sporulation could be induced more readily on seedlings of *Washingtonia filifera* Wendl. than on young date palms. The most favorable environment for the development of sporophores was found to be a moisture chamber in which the temperature was maintained between 26° and 31° C and the relative humidity of the air was held at 92 to 98 per cent.

Freshly discharged basidiospores or bits of gill tissue were planted on corn-meal agar to secure cultures of these fungi directly from the fruiting bodies. These cultures were compared with the ones that had been used in the original inoculations, and, so far as could be determined, each one resembled its respec-

tive parent culture in cultural characters and in pathogenicity (see fig. 12, *B*, *C*, and *D*). Because sporophores were secured on palms which had been inoculated with cultures derived from basidiospores, it was thought that these strains of fungi had been taken through all stages of their respective life cycles.

Comparisons of the fruiting bodies obtained from the different isolates revealed the presence of two distinct species. The pigmented isolates were described (*10*) as *Omphalia pigmentata* Bliss (plate 2), and the nonpigmented isolates were described (*10*) as *O. tralucida* Bliss (plate 3). The principal differences between the two are as follows: The mycelium of *O. pigmentata* resembles glass wool and produces a light-orange-yellow to cadmium (*46*) pigment when grown at 20° to 30° C on slants of 2 per cent glucose potato agar. The sporophores are relatively large (pileus, 5 to 33 mm broad; stipe, 5 to 35 mm long) and tough, while the basidiospores are oval-shaped and measure 6 to 9 by 4 to 6.5 μ. Mycelium of *O. tralucida* may be readily distinguished from that of *O. pigmentata* by a finer texture and the absence of the yellow to orange pigment. The reverse side of the culture may develop a brown to black discoloration. The sporophores are comparatively small (pileus, 3 to 18 mm broad; stipe, 4 to 23 mm long) and fragile, while the basidiospores measure 11 to 16 by 3 to 6 μ and are fusiform-ellipsoidal in shape.

A group of sporophores of *Omphalia pigmentata* (plate 2, *D*) was found on a Saidy date palm at the University of California Citrus Experiment Station, August 29, 1935, after a torrential rainstorm. This is the only instance on record where this species has been observed to fruit on palms in the open. Sporophores of *O. tralucida* have never been collected outside the greenhouse. The absence of sporophores about naturally infected date palms in the Coachella Valley indicates that the spores of these fungi are not usually responsible for the spread of the disease.

In routine laboratory work, *Omphalia pigmentata* and *O. tralucida* may be identified when no fruiting bodies are present. Colonies of both species are white and composed of sterile hyphae having clamp connections. Both species produce necrotic lesions on healthy, unwounded seedlings of date palm. *O. pigmentata* produces the characteristic pigment on slants of glucose potato agar, whereas *O. tralucida* produces no pigment.

Because of the presence of clamp connections in both species, the mycelia of these fungi are thought to be diploid in genetic composition. Cultures derived from groups of basidiospores were similar in appearance and in pathogenicity to cultures from the mycelium. Attempts to culture single basidiospores met with very little success, however. One culture of this kind was obtained from a basidiospore of *Omphalia tralucida*. This colony grew very slowly; in fact, it measured only 8 mm in diameter after 3 weeks at 27° C, whereas colonies of diploid mycelium attained this diameter in 18 hours. The hyaline, sterile mycelium produced many imperfect and apparently nonfunctional clamps at the septa. Small, lateral branches were found which curved over the septa toward adjoining cells without fusing. These single basidiospore cultures gave no evidence of pathogenicity on seedlings of date palm and on *Washingtonia filifera*.

Temperature exerts a marked influence on the growth rate of *Omphalia* spp. Cultures were grown on glucose potato agar at pH 7 in petri dishes 15 cm in

diameter and were incubated in controlled-temperature chambers at 10°, 14°, 19°, 23°, 27°, 31°, and 36° C, respectively. Duplicate cultures were placed in each of the seven temperature chambers, and measurements of three different diameters were made daily on each culture. Except for a slight lag in the initial phase, the curves of average growth rate were practically straight-line functions of time and temperature.

Growth-temperature curves (fig. 18), based on the average radius of col-

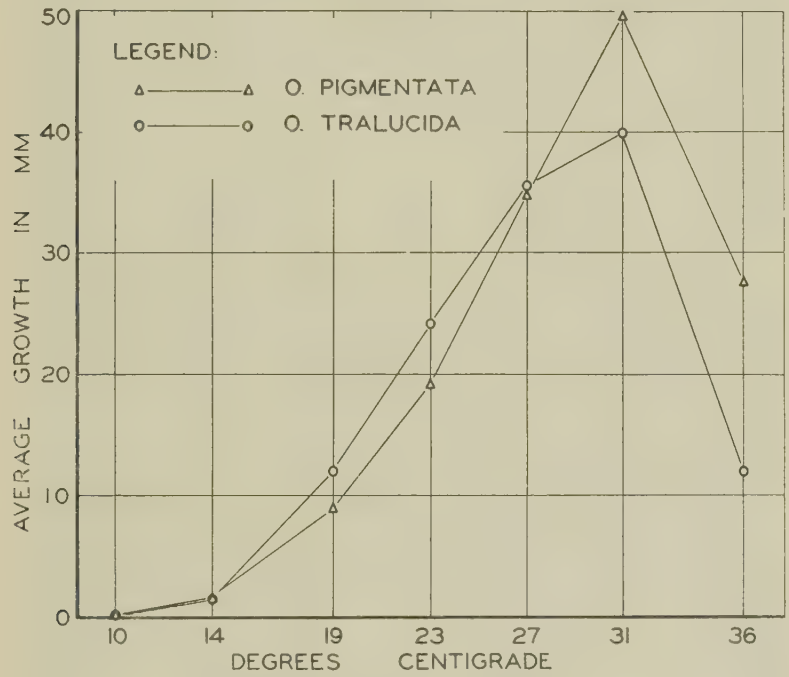


Fig. 18.—Growth-temperature curves of *Omphalia pigmentata* and *O. tralucida* after 99 hours on glucose potato agar.

onies after 99 hours, indicate that the range of temperatures favorable to mycelial growth is from 10° to more than 36° C. Although the optimum temperature for both species is about 31°, it is evident from these data that *Omphalia pigmentata* is favored by slightly higher temperatures than *O. tralucida*. This fact is indicated also by the appearance of the colonies after 140 hours (fig. 19). The three largest colonies of *O. pigmentata* were obtained at 27°, 31°, and 36°, respectively; while the three largest colonies of *O. tralucida* were obtained at 23°, 27°, and 31°, respectively. Temperatures of 10° to 19° produced sparse mycelial development, and at 36° the texture and shape of the colonies indicated an unfavorable effect of a relatively high temperature.

A preliminary experiment[11] should be mentioned regarding the mycelial growth rate of *Omphalia tralucida* on buffered agar. The media contained 0.2 per cent glucose, 0.04 per cent peptone, traces of magnesium sulfate and ferric chloride, and $\frac{1}{10}$ *M* potassium phosphate buffer. Using one petri dish for each

[11] Data supplied by Richard Weindling, October, 1933.

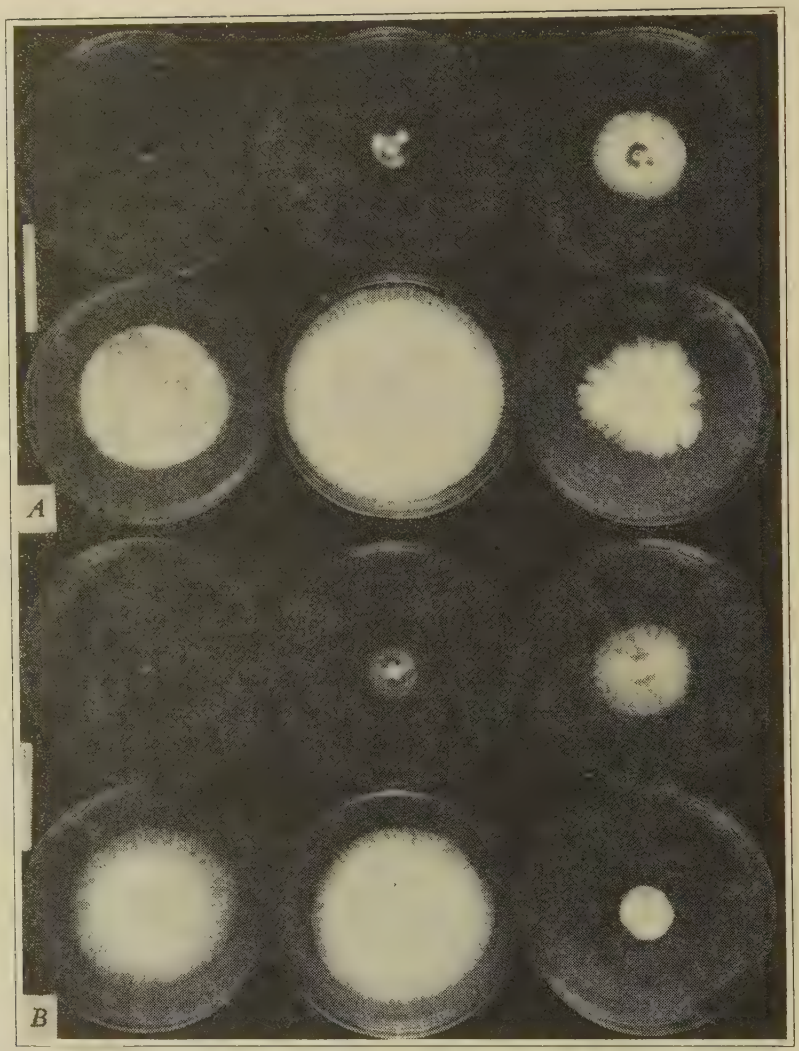


Fig. 19.—Effect of different controlled temperatures on the growth and appearance of *Omphalia pigmentata* (*A*) and *O. tralucida* (*B*) after 140 hours on glucose potato agar. Left to right, upper row: 14°, 19°, 23°; lower row: 27°, 31°, and 36°, respectively.

pH value, and two pieces per dish of omphalia inoculum (3 mm^2) from a culture on glucose potato agar, the following measurements were made after 3 days' incubation at 25° C:

pH	Diameter of colonies, mm
4.0	23–27
5.5	45–46
6.5	34–39
7.5	29–33
9.0	18–19

These preliminary data indicate that although *Omphalia tralucida* will grow on media over a relatively wide range of pH values, most rapid growth may be expected about pH 5.5.

These species of *Omphalia* are facultative parasites (*2*); that is, they can normally go through the whole course of their development as saprophytes, but they also have the power of developing wholly or in part as parasites. Their nutritive requirements as saprophytes are not specific, and no special study of these requirements has been made. These fungi have, however, been

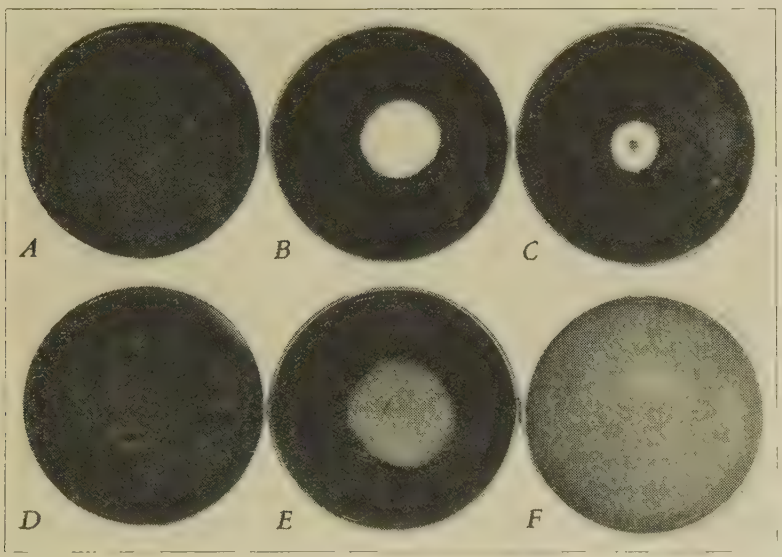


Fig. 20.—Utilization of starch and the production of a starch-dissolving enzyme by *Omphalia tralucida* were demonstrated on Noyes' starch asparaginate agar media by testing with a solution of iodine in potassium iodide. *A*, noninoculated control; *B* and *C*, inoculated with mycelial cultures; *D*, control treated with extract from sterile bran media; *E*, treated with 10 drops, and *F* treated with 10 ml of a filtered extract from a 21-day-old fungus culture on bran. The starch was removed from the areas covered by the fungus cultures (*B*, *C*), and from those covered with the fungus extract (*E*, *F*) as indicated by the iodine test.

grown on several types of laboratory media and on bran, wood, rotted manure, and sterile date roots. They are associated with the soil fungi, but there is as yet no evidence that they are capable of an independent existence in the soil apart from their association with woody materials such as the vegetative parts of the date palm.

Omphalia spp. were grown on media prepared from a variety susceptible to omphalia root rot (Deglet Noor) and from a supposedly resistant variety (Iteema). Decoctions were prepared from the basal portions of two offshoots which had been chopped into small pieces, and agar was added. After the mixtures had been sterilized, the reaction of the Deglet Noor media was pH 5.5, and that of the Iteema media was pH 5.6. The plates were inoculated with several cultures of *O. pigmentata* and *O. tralucida* and incubated 190 hours at

25° C. The size and appearance of the colonies showed no important differences attributable to the kind of media.

The ability of *Omphalia* spp. to produce a starch-dissolving enzyme was clearly demonstrated in petri-dish cultures of Noyes' starch asparaginate agar. After an incubation of 70 hours at 31° C, a test with a solution of iodine in potassium iodide revealed that no starch remained in the agar beneath the colonies, whereas the agar beyond the outermost hyphal tips gave a positive starch test (fig. 20). Furthermore, the water extract of a 21-day-old culture of *O. tralucida* produced similar effects. Ten drops of the extract placed at the center of a sterile plate of starch asparaginate agar removed all starch from the agar in the underlying area during a period of 20 hours at room temperature (fig. 20).

The longevity of omphalia is of interest both from the standpoint of disease control and because of the problem of retaining viable cultures in the laboratory. The base of a detached date leaf, when taken from soil in garden *T*, was completely permeated with viable mycelium of *Omphalia pigmentata*. This discovery suggested the possibility that omphalia might exist on woody tissues in the soil for considerable periods, and also that the pathogen might be spread on such pieces of infested material. Whereas the mycelium of *O. tralucida* had remained viable for two years in date-root segments in moist potting soil, that of *O. pigmentata* had remained alive for an equal period in a block of air-dry wood from the base of an infected palm. Culture B–144 isolated from this dry material proved to be as pathogenic as culture 1803, which had been isolated two years previously from the fresh material. The probability that *O. pigmentata* is more tolerant than *O. tralucida* to unfavorable environmental conditions is indicated by the comparative vitality of numerous stock cultures of both species. When transferred every 6 months to fresh slants of glucose potato agar, incubated for 2 weeks at 25° to 31° C, and later refrigerated at 5°, all cultures of *O. pigmentata* have remained viable, but 12 of 20 cultures of *O. tralucida* have become nonviable under similar conditions.

SUSCEPTS

So far as is known, the number of suscepts of the omphalia-root-rot fungi is very limited. The date palm, *Phoenix dactylifera* L., is the only naturally infected suscept from which these organisms have commonly been isolated. *Omphalia tralucida* was found on one occasion in a necrotic root of jujube, *Zizyphus Jujuba* Mill., but it was not certain that omphalia had been the primary cause of death.

The susceptibility of the native fan palm, *Washingtonia filifera* Wendl., and of the ornamental date palm, *Phoenix canariensis* Chaub., to *Omphalia pigmentata* and *O. tralucida* has been demonstrated by artificial inoculations. Other inoculations on seedling palms of *Butia* (?), *Sabal,* and *Cocos* gave negative results.

In areas where omphalia root rot occurs, only the date palms have been found to be affected. Interplanted citrus trees have shown no indication of disease. In fact, citrus trees in the diseased areas have usually been larger and more vigorous than those in the healthy areas. These differences may be attributed to the supposition that diseased palms offer less competition than healthy

ones. Artificial inoculations produced damping-off in young seedlings of grapefruit, *Citrus paradisi* Macfadyen, but older seedlings with woody stems were not affected.

Bermuda grass, *Cynodon Dactylon* Pers., is one of the most common weeds in the date gardens and is often found about the bases of diseased palms. There is no indication from observation in the field or from artificial inoculation that this plant is affected by omphalia.

The possibility that the omphalia-root-rot fungi are indigenous to the Coachella Valley has led to a search for these organisms on the native plants. Thus far such efforts have been futile. When transplanted and artificially inoculated with *O. tralucida,* several species of desert plants, including the creosote bush, *Larrea tridentata* Cov. var. *glutinosa,* and the California incense plant, *Encelia farinosa* Gray, showed little or no effect. The fungus lived saprophytically in the outer bark of the roots for a period of 9 months but caused no appreciable injury.

DEVELOPMENT OF THE DISEASE

PATHOGENESIS

Since the lesions of omphalia root rot are mostly confined to the underground portions of the date palm, it has not been possible to follow consecutive stages of pathogenesis on any one affected tree. Instead, the life history of the pathogen has been fitted together from many isolated observations. The present concepts of the incubation and infection stages have come from studies on artificially inoculated plants. Other valuable information has been obtained in the field from naturally infected palms.

Incubation Stage.—The incubation stage of omphalia (*6*) has been studied on young seedling date palms. The fungus first grows on the surface of the suscept and forms a loose network of hyphae. It then forms mats of closely woven hyphae connected by more or less definitely organized mycelial strands. These bundles of hyphae (fig. 2, *B*; plate 4, *A, B*) are white at first but they darken with age. They branch irregularly and are often flattened against the surface of the plant. They are associated with an abundance of mycelial growth and seem to grow only along the surface of an organic substrate. Although these strands may be considered rhizomorphs from their function and general appearance, they do not possess a definite structure such as that of the rhizomorphs of the oak-root fungus, *Armillaria mellea* (Vahl) Quel. The mycelium of omphalia grows between the layers of leaf bases; it enters all openings and penetrates cracks and folds. Likewise, it grows along the surface of the roots and upward to the basal node, even through wounds made by the roots themselves in the leaf bases. Up to this stage the fungus is entirely external and, since it is a facultative parasite, it utilizes organic materials outside the plant.

Infection Stage.—As the mycelial mats of omphalia become closely attached to the epidermis of the leaf base, a transformation begins in the underlying cells of the palm. The starch grains are dissolved, and the cells develop a yellowish to brownish discoloration. Finally, the cells die and assume a dark-brown color. A necrotic lesion forms, with a mat of fungus hyphae on its

surface. Hyphal tips on the underside of the mat then penetrate directly through the cuticle and the outer epidermal wall. Nonwounded plants are attacked as readily as wounded ones. The fungus digests the contents of each cell, and by rapid growth fills the cellular cavity with mycelium. This process of penetration proceeds from cell to cell (plate 4, *C*, *D*, *E*) until considerable portions of the leaf base may be filled with the fungus.

It is important to note that the mycelium of omphalia does not penetrate living cells. The discoloration and death of cells beneath the mycelial mat (plate 5, *A*)[12] is suggestive of some enzymatic action. As previously stated (see, "The Causal Organisms," p. 47), in pure culture omphalia secretes a starch-digesting enzyme. The action of this enzyme can be plainly seen by examining a transverse section through a lesion in a young leaf base (plate 5, *B*). The number and size of starch grains are greatly reduced within the discolored cells, and this digestive process may also be detected in an adjoining zone of hyaline cells. The fungus is apparently capable of digesting and absorbing food through the unwounded surface of the host. Meanwhile, the affected tissues are killed and are in some way conditioned for penetration by the fungus at a later time.

Numerous lesions, 2 to 10 mm in diameter, may form on the outer leaf bases of young seedling palms. Sections through such lesions showed, on one occasion, that omphalia had penetrated the epidermis and had entered small cavities and surrounding cells in parenchymatous tissue. The cells immediately below the fungus mat were very dark brown and perhaps filled with gum. At the sides of the lesion, and also below that portion containing fungus mycelium, were empty brown cells that appeared to be dead. Surrounding these was another zone of empty but light-colored cells, which in turn were surrounded by normal cells filled with many starch grains. The partial collapse of the invaded cells seemed to have caused a sunken area at the center of each lesion.

After the fungus becomes established within the tissues, it tends to spread. Several lesions in the same leaf base may coalesce and kill the leaf. Such lesions are usually limited to the underground or basal portion of the leaf but, when that portion is completely invaded, the blade of the leaf wilts and dies from the effect. In young seedling palms (fig. 12, *A*) the fungus first rots the outer sheath, which constitutes the vascular connection with the seed. The oldest and outermost leaf is next affected. This process may continue in small seedlings until the fungus kills the terminal bud, but in older seedlings (and in rooted offshoots also) such invasion is not common. Several factors are involved: Seedling palms become more resistant to attack as they grow older and larger. To reach the terminal bud, the fungus must penetrate more layers of leaf

[12] The photomicrographs shown in plates 5 and 6 are each composed of several smaller prints fitted together. These compound photomicrographs represent a technique which was developed by the writer from methods used in aerial mapping. Whereas overlapping photographs are taken from the airplane as it flies back and forth at a uniform elevation, overlapping photomicrographs are taken as the field is moved beneath the microscope. Prints made from the negatives are fitted together by superimposing the image of one print on the overlapping portion of the adjoining print. The two prints, placed on a cutting board, are cut simultaneously; after the overlapping portions are discarded, the remaining parts fit together almost exactly. By this means it is possible to photograph, at any desired magnification, objects which are too large to be viewed as a whole through the microscope.

bases; and by the elongation of the trunk, the terminal bud is raised above the soil line.

The tightly folded, innermost leaves of the seedling palm are especially susceptible to omphalia. The fungus grows between the folds of the leaves, which, in the region of the terminal bud, are not cutinized. In one instance, sections of the youngest leaf showed browning and necrosis of tissues in the region where the mycelium had penetrated and where the newly formed epidermal layers were just cracking apart. Some mycelium had already entered these cells. A discolored streak, which included plugged vascular elements, was traced downward to the basal node and into two primary roots. This streak was suggestive of some toxic agent which might be carried through the vessels.

The attack of omphalia on the leaf bases of a palm is, in most cases, only a preliminary stage in the more important root-rot phase of infection. Except in the youngest seedlings, there are dead or devitalized tissues about the bases of the palms, where the fungus first becomes established. The older leaf bases, which cover the lower end and sides of the trunk, constitute a physical barrier through which all roots except the original tap root of the seedling must penetrate before they reach the surface. Eventually the bulk of dead leaf-base material in the root zone becomes rather large, and it is here that omphalia develops rapidly during the incubation stage. The young primary roots are often infected and killed as they attempt to penetrate these old, fungus-infested leaf bases (plate 1, *A*). Other primary roots that have already reached the soil may be attacked near the point of contact with the trunk (plate 1, *C*). Omphalia is commonly found in the crevices about the base of the primary roots. Superficial decay of the trunk may follow direct mycelial invasion at these points or may be caused by the inward growth of the fungus through a diseased root. Omphalia has been cultured from the trunk of palms to a depth of 2 cm below the surface (figs. 2, *A* 15, *A*, and plate 1, *A*). Such incasion in small plants results in death. In older palms the fungus does not reach the terminal bud, but it causes serious injury by killing those superficial tissues in the trunk which contain the root primordia. Apparently, the most damaging effect of omphalia on the date palm is the abortion of young roots.

Omphalia may also produce localized lesions in the roots in other locations. The process of mycelial invasion is similar to that already outlined in regard to leaf-base lesions. From a rhizomorph (plate 4, *A*) or mycelial mat, the fungus penetrates directly through the outer integument. It invades all the tissues of the root and fills the cells and air spaces with masses of mycelium (plate 4, *C, D*). The hyphal tips seem to pierce the cell walls without difficulty, especially the thin-walled cells of the cortex (plate 4, *E*). Penetration may also take place through the tiny slits which occur naturally in the cell walls. As in the leaf, the cells become discolored and necrotic before they are invaded by the pathogen. The plugging of the vascular elements (plate 6, *A*) with a dark, gummy substance very probably interferes with the normal movement of water and food in the root. A healthy root (plate 6, *B*) contains cavities in the cortex, which are thought to function as air ducts in the respiration of the root. These cavities in diseased roots become tightly packed with mycelium, and, when viewed in longitudinal section (fig. 3), are visible to the unaided eye as white streaks. The invaded root tissue is dark brown and is separated from the

white, healthy tissue by a yellowish zone about 2 mm in width. This yellowish zone is even more pronounced about an active lesion in the trunk (fig. 15, *A*).

The young, elongating tip of the root is very susceptible to attack by omphalia. Some resistance to attack is developed in older portions of the root, however, as the outer integument becomes thickened and hardened. Severely affected palms that have remained in a stunted condition for years may have a considerable number of old, hardened roots which seem to be functional and not affected by omphalia. These aged roots apparently maintain the palm more or less indefinitely at a low level of nutrition. After the fungus has more or less completely destroyed the ability of the palm to produce new roots and after the available foods in the necrotic tissues have been utilized, the pathogen may also decline in vigor and be overrun by secondary invaders, such as *Fusarium* spp., *Trichoderma* sp., and so forth. The difficulties experienced by the writer in attempting to demonstrate the presence of omphalia in palms long affected by the disease have led to this conviction.

Roots killed by omphalia may remain in soil for a period of several years while undergoing gradual disintegration. Active lesions (plate 1, *Bb*) are visible at the surface if the root is free from soil. When dry, the surface of an infected Deglet Noor root is lilac gray (*46*); a healthy root, under similar conditions, is chamois-colored. In moist soil, the diseased root becomes a dark reddish brown. The necrotic cortical tissue, although at first rather dry and firm, separates from the outer integument and tends to disappear. Fibrous strands from the cortex and the woody central cylinder remain for many months. The outer integument persists as long as any part of the root. Commonly, a young root will enter the cavity which remains in the soil after the decomposition of an old root and will grow through it for a considerable distance.

LATENT PERIOD

The period of development through which omphalia root rot passes between inoculation and the first visible manifestation is known as the latent period. The latent period in regard to the manifestation of primary symptoms is short, since these symptoms appear at the beginning of the infection stage. Additional time is required, however, for the appearance of secondary symptoms. This may vary from a few days to more than five years. When a susceptible palm is inoculated with omphalia, the latent period depends on the size of the host, the concentration of the inoculum, and the environment. This subject has been studied by artificially inoculating healthy palms, by planting healthy palms in infested soil, and by planting diseased palms in noninfested soil.

Seedling date palms appeared to be most susceptible to omphalia root rot when young. One group of unwounded plants in the two-to-three leaf stage (about 4 months old) was killed within 13 days from the time of inoculation. Many seedlings of the Deglet Noor variety, 4 to 9 months of age, developed secondary symptoms within 6 to 40 days after inoculation. About 30 per cent of the plants showed secondary symptoms of disease in 11 to 15 days (table 7), while 63 per cent developed symptoms within the first 20 days. In these cases, the balance between health and disease had been thrown intentionally in favor of the disease by using relatively large quantities of inoculum on palms in the most susceptible stage of development.

Date-palm seedlings more than one year of age were not usually killed by omphalia root rot. In such plants the latent period ranged from a few months to several years. Certain three-year-old seedlings in the field showed severe primary symptoms and slight secondary symptoms 5 months after inoculation. In the Coachella Valley, where rooted offshoots were artificially inoculated, necrotic lesions developed on the underground parts within 2 months, but no secondary symptoms had appeared after four years, nor had mycelial invasion become general throughout the root system.

The youngest naturally infected palms on record are seedlings (fig. 21) that

TABLE 7

DEVELOPMENT OF OMPHALIA ROOT ROT ON SEEDLINGS OF DEGLET NOOR DATE PALM*

Period, days	Seedlings showing secondary symptoms	
	Number	Per cent
0– 5	0	0.0
6–10	47	16.7
11–15	84	29.9
16–20	46	16.4
21–25	23	8.2
26–30	7	2.5
31–35	6	2.1
36–40	4	1.4
40 and over†	64	22.8
Total	281	100.0

* Seedlings in 5-gallon containers and inoculated at 4 to 9 months of age with *Omphalia tralucida* on Pillsbury's bran, 80 ml per container.

† This class includes seedlings that developed secondary symptoms after 40-day incubation period and also seedlings that were not affected.

had sprouted from date pits beneath a large diseased palm in garden *B*. The inoculum had come apparently from detached segments of some infected roots lying near the surface. Judged from the size of the seedlings, the length of the latent period was not more than 1 or 2 months.

In garden *V*, in 1934, healthy Deglet Noor offshoots were set in an area of omphalia-infested soil, part of which had been disinfected with carbon disulfide. The two groups of palms developed equally for about three years, but those in untreated soil showed a decline in vigor thereafter. Five years after planting, these affected palms had become badly stunted, and *Omphalia tralucida* was isolated from the roots. A similar result was obtained in garden *C*, where, in 1934, healthy Deglet Noor offshoots were planted after the removal of diseased palms. Seven years later both primary and secondary symptoms of the disease were found in the palms growing in untreated soil, but no symptoms were found where the soil had been disinfected. In 1933, in garden *T*, 20 healthy Deglet Noor offshoots were set in orchard spacing between rows of diseased palms, and an equal number were planted in an area in which omphalia had not been found. Until 1938 the average increment of trunk growth of the two groups was about equal. During the next three years, however, the

average growth rate of palms in the diseased area was markedly reduced, while that of palms in the healthy area was accelerated. *O. tralucida* was isolated from roots of stunted palms in the diseased area but was apparently not present in palms of the control. From these observations it seems that, when planted in omphalia-infested soil, healthy, nursery-rooted offshoots of Deglet Noor variety are subject to a latent period ranging from three to seven years.

Some diseased offshoots planted in noninfested soil have died within a few weeks; others have shown no secondary symptoms for several years. In 1934 a



Fig. 21.—Naturally infected seedling date palms and a detached root segment from an omphalia-root-rot area.

new block of Deglet Noor palms was set in garden *N*, in which there was a rapidly spreading area of omphalia root rot. Some of the newly planted offshoots died within 2 months and were found to be badly infected with *O. tralucida*. The offshoots had been taken from palms in the same garden, and, though no exact record of parentage had been made, it is supposed that some were infected when cut from the mother palm.

An early transplanting experiment in garden *V* demonstrates the eventual decline of Deglet Noor offshoots taken from diseased mother palms and also the latent period for such cases. Twenty-two offshoots from diseased palms and 34 offshoots from healthy palms were planted in orchard spacing in noninfested soil. After three years Fawcett and Klotz (*21*) reported that "these transplanted palms have recovered and become healthy normal trees." After five years, however, the writer noted definite primary and secondary symp-

toms of omphalia root rot in most of the palms that had come from diseased parents, while those from healthy parents were disease-free. Comparative measurements of palms in these two groups showed no differences at the end of three years, but after five years were:

Source of offshoots and number of palms	Average height of trunk, in ft.	Average height of tallest leaf, in ft.	Approximate volume of top, in cu. ft.
Diseased palms, 22	1.55	7.66	450
Healthy palms, 34	3.43	13.93	2,686

These results agree rather closely with observations on the development of disease in other plantings where offshoots from diseased mother palms have been used inadvertently. In garden *Q*, a 3-acre block of Deglet Noor palms was set in 1923 with offshoots from an older planting where omphalia root rot occurred. Secondary symptoms of the disease appeared in some of the young palms about 1930. In garden *V*, 4 diseased palms were discovered in an eight-year-old block of Deglet Noor palms, the planting stock for which had originated in a diseased garden. Probably no sign of disease was visible in either the mother palms or the offshoots when the planting stock was obtained. Since the young plantings were supposedly healthy, the symptoms of disease might have been overlooked for several years prior to their discovery.

Omphalia root rot first appeared in the Coachella Valley in 1921 in a garden set with palms brought as offshoots from French North Africa about 1915. The disease appeared in 3 other gardens in the Valley within eight or ten years from the time of importation of the palms. Although it is possible that these imported offshoots contracted the disease after arrival in this country, it is also possible and perhaps more probable that certain palms carried the pathogen from the Old World. At any rate, the length of the latent period of the disease in palms of the original plantings was similar to that in younger gardens more recently observed.

DECLINE

After the latent period of omphalia root rot, there is a rather sudden decrease in vegetative vigor of the palm (see "Secondary Symptoms," p. 20). Within three to five years an equilibrium is reached between the pathogen and the suscept, whereby the diseased palm continues to live at a very subnormal level of health. Palms at the center of an old root-rot area exemplify this condition (fig. 7).

Several areas of diseased palms have been observed at yearly intervals for a period of ten years or more. Affected palms in garden *G*, where omphalia root rot was first discovered, have been retained with the hope that their condition might eventually improve. These palms, growing under favorable cultural conditions, have produced no fruit that was worthy of pollination for ten to fifteen years. In garden *Q* the lack of soil fertilization during the period 1929 to 1936, inclusive, seemed to accentuate the decline of affected palms. Strenuous efforts by the owner have since been directed toward improving the condition of these palms. The general appearance of the garden has been improved by means of cultural practices, and even the palms most severely affected by omphalia root rot have now developed some new roots and have a larger, greener top than at any time in the last ten years. A small quantity of rela-

tively poor fruit has been harvested from the diseased palms, but it is still a question whether they will regain enough vigor to become commercially profitable. In most of the affected gardens, however, there has been no perceptible improvement in the condition of diseased palms. These palms have consequently been abandoned or destroyed.

EFFECT OF ENVIRONMENT

The relation of the date palm to its environment was discussed at length by Swingle (*50*). Twenty years later, Mason (*39, 40, 41*) contributed valuable information on the minimum temperature for growth, partial thermostasy of the growth center, and the inhibitive effect of direct sunlight on growth. It was shown by these writers that whereas the date palm will tolerate a relatively wide range of environmental conditions, date culture has succeeded only in the hot, dry regions of the world. Included by Albert and Hilgeman (*1*) in a summary of the essential factors for commercial date production, are: first, a long, hot growing season; second, moderate winter temperatures; and third, little rainfall and low atmospheric humidity during the late summer and fall. Abundant irrigation water and a deep, fertile soil of light texture and of moderately low salt content are other important factors.

The relation of omphalia root rot to environment has been studied in relation to temperature, moisture, pH, and salinity of the soil. Some observations and experiments on these factors will now be discussed.

Temperature.—Air and soil temperatures in the United States Date Garden, Indio, California, were recorded by Bliss, Moore, and Bream (*13*) during the period from September, 1934, to January, 1939. The range of temperatures during this period was as follows:

	Fahrenheit	Centigrade
Air	14° to 114°	−10° to 45°
Soil:		
1-foot depth	40° to 92°	4° to 33°
3-foot depth	54° to 87°	12° to 30°
4-foot depth	53° to 81°	11° to 27°
6-foot depth	59° to 78°	15° to 26°
7½-foot depth	61° to 77°	16° to 25°
8-foot depth	65° to 77°	18° to 25°

Of the date roots found in the upper 8 feet of soil, more than 97 per cent (by weight) were encountered in the zone between 1 and 6 feet.

The effect of different controlled soil temperatures on disease development and on growth of the date palm, was studied in the greenhouse by means of five soil-temperature tanks (fig. 22). Water baths were heated in the tanks by electric soil-heating cable; three baths were also cooled by means of mechanical refrigeration. The seedling palms were grown in soil of light, sandy loam, in metal pots, 8 inches in diameter and 12 inches tall. These metal pots were inserted through holes in the tank lids and submerged to a depth of 8.5 inches in the water baths. Since there was no drainage from these pots, the soil was irrigated with distilled water to avoid excessive accumulation of salts. The soil moisture content was maintained within the range between the permanent wilting percentage and field capacity by adding water at frequent intervals to

raise the total weight of each pot to a certain predetermined level. All the seedlings were grown at first on a bench in the greenhouse under similar environmental conditions. At the time of inoculation, the pots were set in the soil-temperature tanks where they remained until the end of the experiment.

Equipment of the United States Department of Agriculture had been used in three preliminary experiments through the courtesy of J. L. Weimer. In the



Fig. 22.—Inoculated seedling date palms in five soil-temperature tanks. Controlled temperatures were maintained from 10° to 38° C by means of electric soil-heating cable and a mechanical refrigeration machine.

five principal experiments conducted in new soil-temperature tanks just described, the temperatures of the water baths were considerably more constant than those of the preliminary trials. Experiments nos. 4 and 5 with *Omphalia tralucida* and *O. pigmentata*, respectively, will be described in detail as representing the best examples of the kind of results obtained.

Temperatures were maintained at 7-degree intervals between 10° and 38° C. The weekly mean temperatures of the water baths (fig. 23), calculated from 11 to 17 readings per week, reflected the satisfactory performance of the

equipment during a period when the weekly mean air temperatures, obtained from thermograph charts by the planimeter method (*13*), ranged from 18° to 26° C. The temperatures of the soil at the surface of the pots, however, sometimes varied as much as 2 or 3 degrees from the temperatures of the corresponding water baths because of the wide gradient between air and water temperatures. These unavoidable differences probably influenced the accuracy of the results, especially those at 10° and 38°.

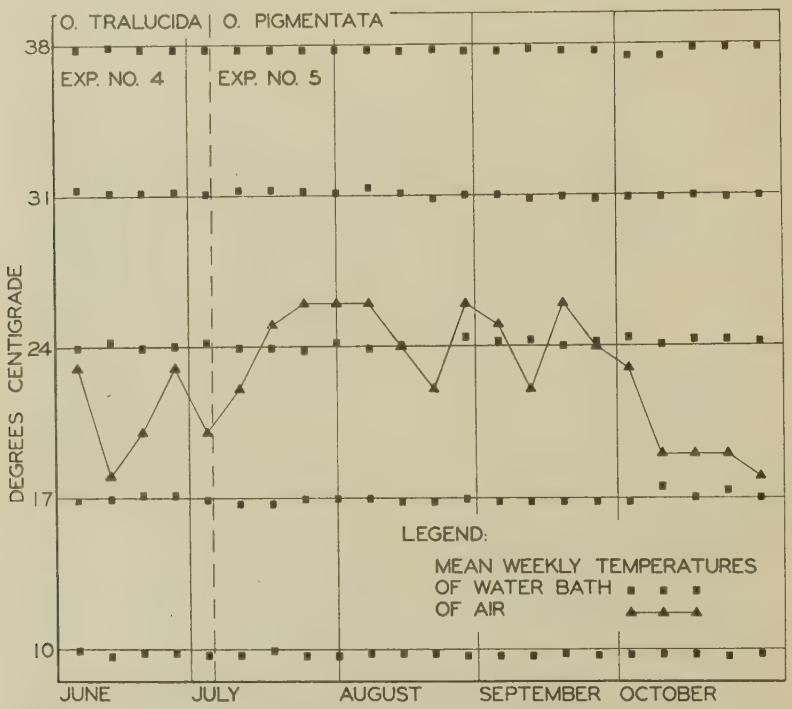


Fig. 23.—Mean weekly temperatures of the five water baths and of the air during the period of soil-temperature experiments (no. 4 and no. 5), in which seedling date palms were inoculated with *Omphalia tralucida* and *O. pigmentata*, respectively.

In experiment no. 4, twenty-one 140-day-old Deglet Noor seedlings were inoculated with *Omphalia tralucida* and placed in each of the five soil-temperature tanks. Secondary symptoms appeared after 7 days in plants at 24° and 31° C (fig. 24). Disease development at 24°, 31°, and 38° was very rapid thereafter, and 100 per cent of the seedlings at 31° showed symptoms within 19 days. A longer latent period and less rapid disease development was noted in plants at 17°. No secondary symptoms appeared in plants at 10° during the 36-day period of the experiment. Examination of the roots revealed severe injury to plants at 24° to 38°, moderate injury to those at 17°, and only slight injury to those at 10°. The optimum temperature for disease development with *O. tralucida* appeared to be 31°.

In experiment no. 5, sixteen 176-day-old Deglet Noor seedlings were inocu-

lated with *Omphalia pigmentata* and placed in each of the five soil-temperature tanks. Secondary symptoms appeared at 31° and 38° C after 8 days (fig. 24), but disease development at all temperatures was less rapid than had been

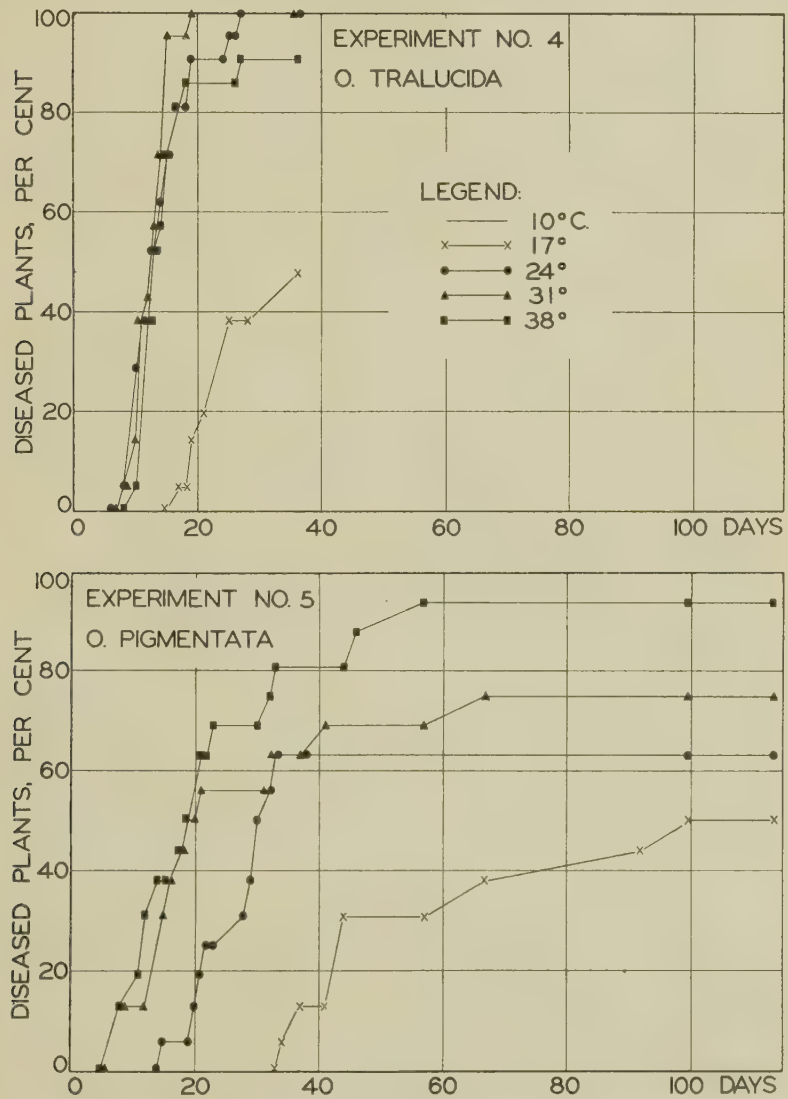


Fig. 24.—The effect of different controlled soil temperatures on the percentages of inoculated date seedlings with secondary symptoms of omphalia root rot in relation to time. Experiment no. 4 with *Omphalia tralucida*; experiment no. 5 with *O. pigmentata.*

observed with *O. tralucida* in experiment no. 4. During the 111-day period of the experiment, secondary symptoms had appeared at all temperatures except 10°. Examination of the underground portions revealed that the most severe

root injury had occurred at 31°, though moderately severe injury had also developed at 17°, 24°, and 38°. No root injury and only small lesions in leaf bases were found at 10°. These observations indicate that the optimum temperature for disease development with *O. pigmentata* is 31° or slightly above.

All control plants in the above-mentioned experiments remained healthy so far as omphalia root rot is concerned. Considerable effect was noted, however, in the size of these plants because of the differential soil-temperature treatments. Plants, when moved from the greenhouse bench to the soil-temperature tank at 10° C, underwent slight wilting and seemed to remain in a more or less static condition for the duration of the experiment. Such was the case in experiment no. 5 (table 8). The seedlings, at the beginning of this experiment,

TABLE 8

EFFECT OF DIFFERENT CONTROLLED SOIL TEMPERATURES ON THE GROWTH OF NONINOCULATED DEGLET NOOR SEEDLING DATE PALMS*

Soil temperature	Plants	Average diameter of basal node	Average number of green leaves	Average length of longest leaf	Average number of primary roots	Total length of primary roots
°C	*number*	*mm*	*number*	*cm*	*number*	*cm*
10	5	11.6	4.4	37.2	2.0	42.6
17	6	11.8	5.2	41.8	2.8	60.8
24	6	12.4	5.7	54.5	3.2	96.8
31	6	13.8	6.7	58.8	3.7	92.8
38	6	12.8	6.0	64.3	3.2	60.8

* Palms were grown for 111 days in soil-temperature tanks. They were 6 months old and of uniform size at the beginning of the differential treatments.

were 6 months old and of uniform size. Differences in the average measurements of these seedlings after 111 days indicate that under these conditions 24° was the optimum temperature for the elongation of primary roots, that 38° was conducive to greatest elongation of leaves, and that thickening of the basal node was greatest at 31°. In experiment no. 1 root elongation had been inhibited at 40°. These results, though based on insufficient data to warrant a general conclusion, indicate that terminal growth of date roots is limited to soil temperatures between 10° and 40° C (50° to 104° F), and that the optimum temperature is about 24° C (75° F). Indications are also that both the date palm and the omphalia-root-rot fungi are best adapted to relatively high soil temperatures such as those found in the Coachella Valley during the summer months.

Moisture.—Date palms tolerate a wide range of soil moisture conditions. In the Coachella Valley there are date palms in soil which has probably received no artificial irrigation for twenty years. These palms have survived either because of moisture stored during the infrequent rainy seasons or because deep-lying roots have contacted underground moisture. The tops of these palms have become much reduced in size, and terminal growth of the trunk has nearly ceased. On the other hand, date palms will remain alive for considerable periods in soil that is covered with water. Milne (*43*) illustrates two large but sickly-appearing palms whose bases had been immersed continuously

for six years. Bowers (*14*) pictures a palm of *Phoenix canariensis* which stood for twelve years in the water of a reservoir on Santa Catalina Island.

The effect of continued immersion of the roots of seedling date palms was observed in the greenhouse. Eleven-month-old seedlings that were growing in



Fig. 25.—Seedling date palms showing the effect of root immersion for a period of three years: nonimmersed control (left); immersed (right). The metal containers were removed to show the condition of the roots.

two 5-gallon containers in fine sandy loam were lowered into large earthenware crocks. One crock was filled with water so as to saturate the soil and immerse the roots. Plants in the other crock (control) received only enough water to moisten the soil. These conditions were maintained for a period of three years. There was no drainage from the crocks and no chemical fertilizers were added

except those found in the irrigation water. At the end of the period (fig. 25) all the plants were alive but they were chlorotic because of nitrogen deficiency. The plants that had been standing in water were severely stunted, and the older leaves were burned at the tip because of salts which had become concentrated in the water and which had crystallized on the leaf bases. Samples of water from this crock indicated pH 7.52 near the top and pH 7.49 near the bottom. The leachate from the control pot registered pH 9.28. Roots in both containers were severely pot bound. They were concentrated about the periphery of the soil mass and especially at the upper surface where they appeared to serve as organs of respiration. Only a few of the immersed roots remained alive at the bottom of the container, most of the living roots being near the upper surface. Nearly all the roots were alive in the control.

In another experiment, Deglet Noor seedlings were grown in fine sandy loam in 5-gallon containers. When the plants were 4 months old, the twelve containers were divided into three equal groups and inoculated as follows: the first group (control) received only sterile bran; the second, *Omphalia pigmentata* on bran; and the third, *O. tralucida* on bran. Two pots from each group were immersed in water after 48 hours from the time of inoculation and the others were watered in the usual manner. The period of immersion was terminated 4 months later, and plants in the even-numbered pots were taken up for examination. There were no disease lesions on plants whose roots had been immersed, but there was a high degree of infection on the other inoculated plants. All control plants were healthy. A similar result was noted when, 3 months later, the remaining plants were examined. Apparently, immersion of roots 48 hours after inoculation had prevented infection completely. Roots in the saturated soil had darkened at the surface, and secondary roots near the basal node had turned upward as if seeking the air.

In the field at various times the soil in omphalia-root-rot areas has been observed to contain more moisture than that in nonaffected areas. Because of their reduced root system, diseased palms would not utilize the available soil moisture as rapidly as would healthy palms. It is not known whether, under field conditions, the continuous saturation of soil about diseased palms for long periods would reduce the spread of omphalia. It would seem, however, that the date palm is more tolerant of saturated soil than are the species of *Omphalia* that cause this root rot.

A certain amount of moisture is of course necessary for both the palm and the pathogen. Soil moisture permits the development of omphalia within the underground portions of the palm but the usual lack of moisture aboveground sharply delimits the upward spread of the fungus in the tree. Under artificial conditions, such as those in which *Omphalia tralucida* was induced to sporulate (plate 3), the mycelium did not remain under the soil but spread upward throughout the leaf bases. This extension of the mycelium was stopped when the plants were removed from the moisture chamber.

pH of the Soil.—In order to study the pH values of soils in which date palms are growing, determinations were made in the field and in the laboratory on samples from 5 gardens in different parts of the Coachella Valley.[13] Methods described by Haas (*27*) and by Haas and Compton (*28*) were employed. Using

[13] All determinations of pH mentioned in this section were made by A. R. C. Haas.

a soil tube, composite samples were obtained from 3 holes and at 5 different depth intervals between 0 and 4 feet. Each fresh composite sample was placed immediately in a tin container and mixed vigorously with a horn spoon. The sample was then transferred to a Pyrex beaker and a reading was taken by means of a Beckman pH meter (laboratory model G) with a shielded glass electrode and a sealed calomel electrode. Because of the disturbance of the gaseous soil phase and the loss of carbon dioxide from the sample upon stirring, the pH value may possibly have been considerably higher than it would have been if the determination had been made *in situ*. The same sample was then placed in a closed soil container and taken to the laboratory, where a second determination of pH was made using a 1:5 ratio of soil to water. Moisture equivalents were also determined on most of the samples.

Under the conditions of these determinations, soils in the 5 date gardens of the Coachella Valley ranged from pH 6.60 to 7.94 at field moisture content and from pH 7.84 to 9.83 at 1:5 ratio (table 9). In orchard no. 3, soil samples taken from a part of the date garden not showing diseased trees gave nearly the same pH values as other samples which were taken within an area affected with omphalia root rot. There appears to be a fair degree of uniformity in the pH values of the soils that were tested in the Indian Wells, Indio, Thermal, and Oasis districts.

An inoculation experiment was conducted in the greenhouse on potted Deglet Noor seedlings growing in soil at different pH levels. Tujunga fine sandy loam (pH 8.10 at 1:5 ratio of soil to water) and dried blood meal (1 per cent by weight) were screened and mixed together thoroughly. On the basis of preliminary tests, the following amounts of sulfuric acid and sodium hydroxide were added to 50 pounds of air-dry soil to produce the desired pH values:

Reagent	Volume, ml	pH of soil
N sulfuric acid	4,387.3	3.0
0.50*N* sulfuric acid	4,463.0	5.0
0.10*N* sulfuric acid	3,782.2	7.0
0.05*N* sodium hydroxide	3,025.7	9.0
0.20*N* sodium hydroxide	4,538.6	11.0

The chemical solutions were mixed thoroughly with 50-pound lots of soil. Five-gallon metal containers, without drainage holes and covered with an asphalt roofing paint, were used as pots. Thirty pots of soil were prepared, 6 for each pH level. The total weight of each container was adjusted and maintained at 62 pounds by the addition of distilled water (pH 5.19).

Soil samples were taken for pH determinations 2, 56, 174, and 402 days, respectively, after the pH values had been adjusted (table 10). Two or three cores, about 1 cm in diameter and extending through the soil from top to bottom of the container, were taken for each determination. The soil was dried at 40° to 50° C. To 30 grams of dry soil was added 150 ml of distilled water. The mixture was stirred several times for a period of 2 hours after which the pH value was measured. Considerable change was found in the pH levels of the soil, even within 2 days from the time of initial adjustment. There was a tendency for the pH level of soil in all the lots to shift somewhat closer to pH 8.10, the original level of the soil before treatment. After 402 days, the extreme range of pH values was from 4.13 to 8.03, although, when determined at the

TABLE 9

REACTION OF SOILS IN FIVE DATE ORCHARDS IN THE COACHELLA VALLEY

Orchard no., locality, soil type,* condition of palms, and depth interval of soil	Moisture equivalent	Soil reaction	
		At field moisture content (in beaker)	At 1:5 soil–water ratio
	per cent	*pH*	*pH*
1. Indian Wells, Coachella fine sand			
Healthy			
0.0–0.5 feet	9.5	7.60	8.71
0.5–1.0 feet	9.5	7.90	9.10
1.0–2.0 feet	9.7	7.91	9.17
2.0–3.0 feet	9.9	7.86	9.17
3.0–4.0 feet	6.6	7.90	9.00
2. Indio, Coachella fine sand, smooth phase			
Healthy			
0.0–0.5 feet	11.6	6.60	7.84
0.5–1.0 feet		7.11	8.26
1.0–2.0 feet	16.9	7.43	7.96
2.0–3.0 feet	36.7	7.50	8.36
3.0–4.0 feet		7.46	8.32
3.† Indio, Indio very fine sandy loam			
Healthy			
0.0–0.5 feet		7.01	8.40
0.5–1.0 feet		7.62	8.77
1.0–2.0 feet		7.70	8.90
2.0–3.0 feet		7.51	8.66
3.0–4.0 feet		7.51	8.11
Diseased (omphalia root rot)			
0.0–0.5 feet	18.3	7.43	8.30
0.5–1.0 feet	17.0	7.71	8.83
1.0–2.0 feet	12.9	7.63	8.86
2.0–3.0 feet	6.8	7.70	8.91
3.0–4.0 feet	6.4	7.64	9.03
4. Oasis, Indio very fine sandy loam			
Healthy			
0.0–0.5 feet	18.6	7.51	8.45
0.5–1.0 feet	22.5	7.50	8.70
1.0–2.0 feet	12.5	7.60	9.03
2.0–3.0 feet	9.5		9.56
5. Thermal, Indio very fine sandy loam			
Healthy			
0.0–0.5 feet	13.5	7.43	8.96
0.5–1.0 feet		7.80	9.13
1.0–2.0 feet	19.2	7.61	9.23
2.0–3.0 feet	25.9	7.94	9.21
3.0–4.0 feet		7.80	9.83

* Classification of Kocher and Harper (*37*).
† Garden *K*.

existing soil-moisture percentage, the pH of the same soils ranged from 3.84 to 7.11. Soil in the containers of the same pH group exhibited considerable uniformity when compared at different times throughout the experiment. Although there were shifts away from the original pH levels, the levels of the different groups remained distinct and in the same order as at the beginning.

Nine young seedlings of Deglet Noor date palm were transplanted to each of the 30 containers 56 days after adjustment of the soil. These seedlings were grown in the greenhouse at a minimum air temperature of 80° F. The soil was inoculated in the usual manner after 174 days with *Omphalia* spp., and, finally, the plants were taken up at the end of 432 days.

TABLE 10

REACTION OF ARTIFICIALLY ADJUSTED SOIL USED IN THE INOCULATION EXPERIMENT WITH *Omphalia* SPP.

Inoculation no.	At 1:5 soil-water ratio					At existing moisture content	
	Initial	After 2 days	After 56 days	After 174 days	After 402 days	Soil moisture	After 402 days
	pH	*pH*	*pH*	*pH*	*pH*	*per cent*	*pH*
1477	3.0	4.25	5.74	4.77	4.20	30.7	3.87
1478	3.0	4.25	5.42	4.74	4.13	21.8	3.96
1479	3.0	4.28	5.30	4.84			
1481	3.0	4.30	5.65	4.94	4.30	29.3	3.84
1482	3.0	4.46	5.57	4.50	4.15	34.5	3.89
1483	3.0	4.40	5.43	4.70			
1485	5.0	6.83	6.93	5.11	5.22	22.6	5.33
1486	5.0	6.98	7.20	5.54			
1487	5.0	7.15	7.00	5.13	5.23	22.0	4.90
1490	5.0	6.95	7.22	5.51	5.03	18.6	5.10
1491	5.0	7.03	6.70	5.57			..
1492	5.0	7.00	7.02	5.27	5.37	27.9	5.13
1493	7.0	8.20	7.77	6.90			.. .
1494	7.0	8.11	7.43	7.00	6.87	21.9	6.37
1495	7.0	8.17	7.72	7.03	7.00	21.3	6.60
1497	7.0	8.07	7.68	6.93	6.90	30.3	6.53
1499	7.0	8.07	7.31	6.87	6.83	21.6	6.66
1500	7.0	8.07	7.78	6.86	..	..	
1501	9.0	8.96	8.60	7.19	7.00	24.1	6.70
1502	9.0	8.94	8.40	7.04		...	. ..
1503	9.0	8.92	8.45	7.11	7.23	23.5	6.62
1504	9.0	8.92	8.51	7.10	7.10	22.5	6.50
1505	9.0	8.92	7.93	7.03			. .
1508	9.0	8.90	8.60	7.19	7.14	22.7	6.53
1509	11.0	9.84	9.65	8.19	7.90	28.1	6.78
1511	11.0	9.75	9.29	7.38		...	
1512	11.0	9.83	9.03	8.10			
1513	11.0	9.75	9.30	8.23	8.03	20.1	7.11
1514	11.0	9.67	9.00	7.80	7.70	26.6	6.64
1516	11.0	9.72	9.26	7.61	7.90	21.6	6.48

This experiment was complicated because of the relatively large number of variables. In soil at the 5 different pH levels, there were 3 kinds of inoculations: first, the control; second, *Omphalia pigmentata* (culture 1803); and third, *O. tralucida* (culture B–181). Interpretation of the results was also complicated by the partially overlapping effects of chemical injury and of omphalia root rot on the development of the seedlings. Only the effects of chemical injury were noted in the controls, but the combined effects of both types of injury were evident in the other inoculations (table 11).

Judging from the size and appearance (fig. 26) of the plants at the conclusion of the experiment, most growth had occurred in soil between pH 5.03 and pH 7.22. Tolerance was demonstrated for a wide range of pH values since there had been growth throughout the pH range, 4.13 to 9.65. Severe tip burning of the leaves had occurred in the pH range, 4.20 to 5.74. Marked stunting and leaf chlorosis had developed from pH 7.90 to pH 9.30. At intermediate

TABLE 11

EFFECT OF PH OF THE SOIL ON THE GROWTH OF DEGLET NOOR SEEDLING DATE PALMS, THE DEVELOPMENT OF OMPHALIA ROOT ROT, AND THE DEGREE OF CHEMICAL INJURY

Inoculum and range of pH values of soil, 1:5 soil–water ratio	Total plants	Dead plants	Living plants							
			Mean diameter basal node	Average green leaves per plant	Longest green leaf per plant, average length	Primary roots, average per plant		Affected with omphalia root rot	Relative severity of lesions	Degree of chemical injury
						Healthy	Aborted			
	number	*percent*	*mm*	*number*	*cm*	*number*	*number*	*percent*		
None (control)										
4.20–5.74	19	58	12.6	4.8	35.9	2.8	0.5	0	none	severe
5.03–7.22	18	28	17.0	7.4	48.5	5.1	0.0	0	none	none
6.87–7.72	16	19	13.3	5.5	39.9	3.5	0.0	0	none	very slight
7.10–8.60	16	25	13.4	5.6	35.8	3.9	0.0	0	none	slight
7.90–9.30	19	16	12.4	4.5	32.9	3.3	0.0	0	none	moderate
Omphalia pigmentata (no. 1803)										
4.70–5.43	18	56	13.4	4.5	37.3	2.3	0.4	50	slight	severe
5.54–7.20	18	56	15.8	4.9	37.8	3.3	1.4	100	severe	none
6.86–7.78	18	28	12.9	5.3	37.0	3.8	0.5	77	moderate	slight
7.03–8.40	16	25	11.5	4.4	31.5	2.8	0.5	67	moderate	slight
7.38–9.29	18	33	11.9	3.8	37.5	2.0	1.4	92	severe	moderate
O. tralucida (no. B-181)										
4.13–5.57	15	60	12.6	3.5	37.5	1.7	1.3	17	very slight	severe
5.11–7.02	17	47	15.6	5.5	39.1	2.8	1.2	100	moderate	none
6.83–7.68	16	63	16.1	5.2	47.8	3.0	1.5	100	moderate	very slight
7.00–8.60	14	43	12.6	5.1	36.3	3.6	0.9	100	moderate	slight
7.70–9.65	17	76	10.1	2.5	28.5	1.3	2.0	100	severe	severe

levels, especially pH 5.03 to pH 7.22, there was no chemical injury, and the plants were dark green and vigorous. Very slight lesions of omphalia root rot had developed in certain lots of soil that ranged between pH 4.13 and pH 5.57, but there was moderate to severe infection in other lots of soil that ranged between pH 5.11 and pH 9.65. In this experiment, a higher percentage of infection was obtained from *Omphalia tralucida* than from *O. pigmentata,* but the reaction of the two species to different pH values in the soil was similar.

Soil Salinity.—Among agricultural plants, the date palm is thought to be one of the most tolerant to salinity. Swingle (*50*) and Kearney (*31*), while studying date culture in northern Africa, noted the stunting effect of saline soils and the improvement in plant vigor which resulted when these soils were leached with water to carry the salts below the root zone. Large quantities of salts also occur in some of the soils in the Coachella Valley. Eaton (*17*) calls

attention to the fact that the date palm, although very tolerant to salt, "does not thrive best on, nor so far as we know derive benefit from quantities of salt that are detrimental to other cultivated plants of desert areas."

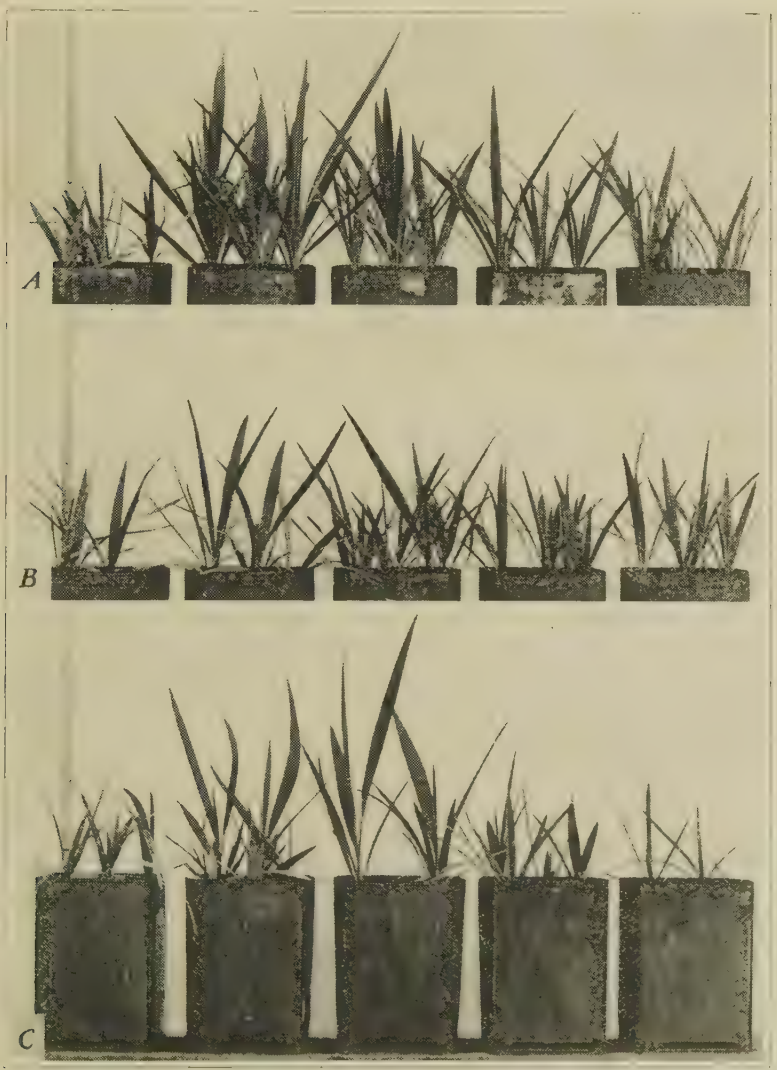


Fig. 26.—Effect of soil pH on the growth of seedling date palms and on the development of omphalia root rot: *A*, noninoculated control plants; *B*, inoculated with *Omphalia pigmentata*; *C*, inoculated with *O. tralucida*. The approximate pH values of the soil at the conclusion of the experiment were (from left to right): 4.1, 5.1, 6.9, 7.1, and 7.9, respectively.

The effect of soil salinity on development of omphalia root rot was studied by means of one-year-old, inoculated Deglet Noor seedlings in the greenhouse. Two types of soil were used, namely: Indio very fine sandy loam (chloride,

10,827 p.p.m. before leaching), and Tujunga fine sandy loam (chloride, 27 p.p.m.). The date seeds germinated poorly in the highly saline soil prior to leaching, but a second planting of seeds produced plants which grew nearly as well as those in the other soil. Eight months after inoculation, omphalia root rot was about equally severe in the two types of soil.

Eighteen varieties of date palms have been infected artificially with omphalia root rot in garden *X* from which the saline soil was obtained for the experiment mentioned above. The upper 1-foot layer of soil contained, in parts per million, at the time of inoculation: carbonate, 0; bicarbonate, 144; chloride, 3,018; sulfate, 6,100; calcium, 1,100; and sodium, 3,622. The pH was 9.0.[14] It is evident, therefore, that omphalia root rot may occur in soils that vary widely in salt content.

SPREAD

Spread from One Focus of Disease.—The spread of omphalia root rot has been followed in certain date gardens over a period of several years by means of annual surveys. A progress report on these was given in a previous paper (*9*).

In 1915, 61 imported Deglet Noor offshoots were planted in garden *T* adjoining, on two sides, other imported date palms of Khustawy, Zahidi, Khalasa, Tafazwin, Deglet Beida, and Halawy varieties. About 1922 the owner noticed that one of the Deglet Noor palms near the center of the planting had become stunted and, that in succeeding years, similar symptoms appeared in near-by palms of the same variety. From 1922 to 1935 the disease spread in ever-widening circles from 1 palm to 60 and finally, all palms of the Deglet Noor variety were destroyed. The rapid spread of omphalia root rot in this garden was studied during the period 1931 to 1934 (figs. 4, 5, 6, 7, 9, and 27). Judging from the first appearance of secondary symptoms, the disease had spread at the alarming rate of 30 to 60 feet per year. Such rapid spread has not been observed elsewhere during the present investigation. The difference in susceptibility of Deglet Noor in comparison with the other date varieties in this garden was striking, since all palms of Deglet Noor were affected and none of the other varieties showed secondary symptoms of decline. Some palms of the other varieties were diseased, however, since in 1937 *Omphalia pigmentata* was isolated from a Zahidi palm and *O. tralucida* was obtained from a Tafazwin.

The spread of omphalia root rot was followed closely in garden *N* during the period 1933 to 1936. Field surveys and laboratory tests were made after three corresponding intervals (fig. 28). In the original diseased area 5 palms were removed in 1933 after *Omphalia tralucida* had been isolated from the roots of 3. Two more palms were visibly affected in 1935. *O. tralucida* was isolated, not only from these, but also from 2 other palms which showed at that time no secondary symptoms, but which were visibly affected a year later. Finally in 1936, root samples were taken from 23 additional palms, 18 of which showed no outward signs of the trouble. At least 8 of these 18 healthy-appearing palms yielded *O. tralucida* in addition to similar cultures obtained from 3 palms with secondary symptoms. These results indicated that root rot precedes the appearance of secondary symptoms, that mere removal of visibly affected palms will

[14] Analyses by B. M. Laurance.

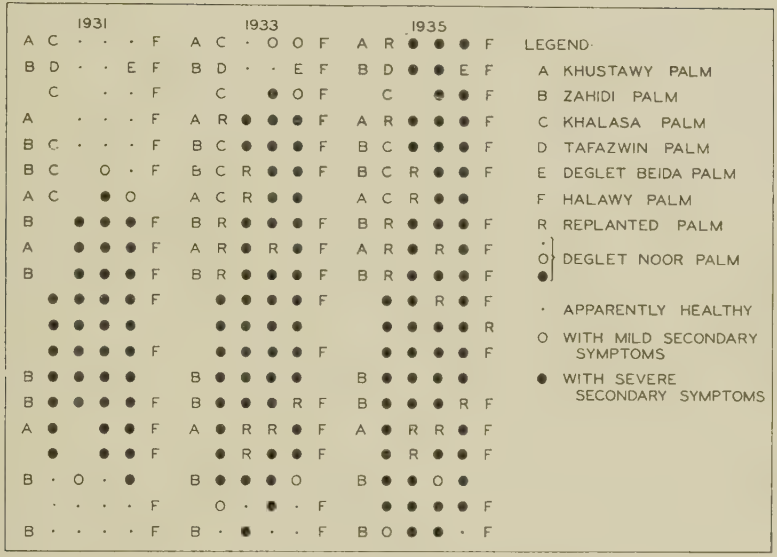


Fig. 27.—Three maps of an omphalia-root-rot area in garden *T*, indicating the visible spread of the disease between 1931 and 1935.

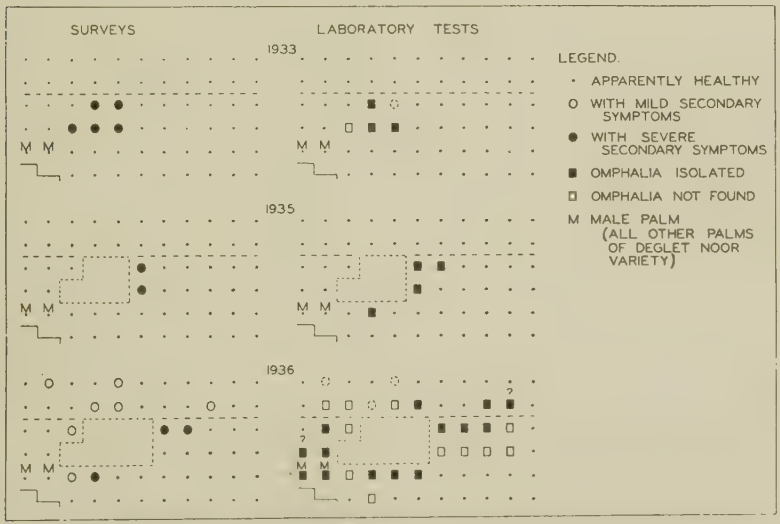


Fig. 28.—Six maps of an omphalia-root-rot area in garden *N*, indicating the spread of the disease between 1933 and 1936. The results of field surveys (left) and laboratory tests (right) are both presented to show that healthy-appearing but infected palms were found at the outer margin of this diseased area. The short dashed lines indicate areas where palms had been removed. The short dashed circles indicate visibly affected palms from which no laboratory tests were made.

not control the disease, and that for delimiting an omphalia-infested area, the laboratory method of diagnosis, as was previously found (*9*), is much more reliable than the survey method.

Fawcett and Klotz (*21*) traced the gradual spread of disease in garden *G* from a single diseased palm in 1921 to 31 palms in 1928. The same area was surveyed annually by the writer from 1931 to 1940, inclusive. Except for relatively high readings in 1934 and 1935, when the cultural tone of this garden was below normal, the total number of visibly affected palms remained fairly uniform (fig. 29). The personal factor is sometimes rather large in surveying for this disease, especially in diagnosing the trouble in palms with border-line

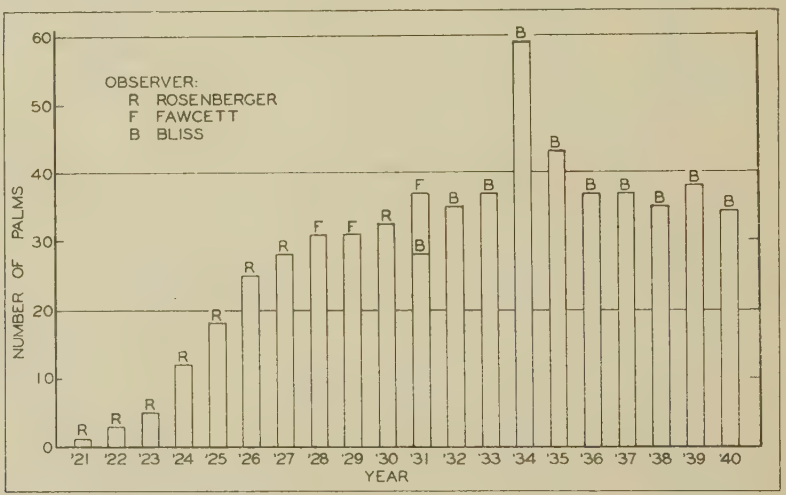


Fig. 29.—Histogram indicating the number of Deglet Noor palms visibly affected with omphalia root rot in garden *G* during the period from 1921 to 1940, inclusive.

symptoms. The presence of many dead leaves may influence considerably the judgment of the observer. Since about the same number of diseased palms were found in the periods 1932 to 1933 and 1936 to 1940, the higher readings of 1934 and 1935 may be attributed to factors other than omphalia root rot.

Three phases may be distinguished in the history of the disease in garden *G*: first, 1915(?) to 1921, the latent period; second, 1921 to 1931, period of rapid spread; and third, 1931 to 1940, period of equilibrium. A similar period of equilibrium was noted in garden *Q* after the cultural treatment of the palms had been improved. An area of about 3 palms in garden *M* did not enlarge after 1933, at which time the poorest palm was removed. Apparently the disease had remained in the phase of rapid spread in garden *T* (fig. 27) until all the Deglet Noor palms had become infected. It is difficult to explain why certain areas became static while others continued to enlarge.

Observations on the spread of omphalia root rot indicated that the causal fungi migrate through soil from palm to palm. Attention was directed, therefore, to the rooting habit of the date palm and to the possibility that the mycelia of these fungi might grow along the roots.

In the Punjab, Milne (*43*) found that about 75 per cent of the roots of a mature date palm in well-drained soil of "medium loam" did not extend beyond a radius of 6 feet from the trunk and only 8 per cent extended more than 10.5 feet in the direction of an irrigation ditch. Many roots ended at depths from 4 to 8.5 feet. In the United States the date roots grow longer. At Tempe, Arizona, Simmons (*47*) found the roots of a mature tree to be 10 to 40 feet in length. One root was followed downward 7.25 feet to a hard pan and thence for 27 feet laterally. Simmons estimated that the roots of one palm may occupy soil beneath 1,800 square feet of surface area.

Similar observations were made by the writer in the Coachella Valley when the primary roots of Deglet Noor palms were traced laterally from the trunk for a distance of 35 feet or more. A trench was dug in garden *K* diagonally across a 30-foot tree square between 2 Deglet Noor palms. (See fig. 11, *C*.) The soil (Indio series) was a very fine sandy loam stratified with clay loam to a depth of 30 to 34 inches and underlain with very fine sand. Some roots that extended directly along the axis of the trench were taken up to their full length in one piece. In this location the principal root-feeding zone was in soil from 12 to 36 inches deep. Very few roots, even of the smaller (or lower) ranks, were found in the first 12 inches. The primary roots, however, were in the sandy layer mostly 36 to 60 inches below the surface (fig. 30, *A*). In diameter, they were rather uniform from one end to the other.

There were many secondary roots extending outward in all directions (both upward and downward) from the primary roots. The roots which lay deep in the sand were roughened and irregular in shape; those above in the loamy soil were comparatively smooth and regular. Since the secondary roots branched off at nearly right angles to the long axis of the parent root, the direction of root growth was sometimes difficult to determine. Some branches bent slightly forward, however, and where forking of the primary root occurred, the acute angle between the forks gave a definite clue to the direction of growth (fig. 30, *B*). Beginning 7 inches from the distal end of one primary root, the secondary roots were spaced on the average of approximately one per inch for a distance of 12 feet. These secondary roots varied in length from 1 inch to 2 feet or more. Those growing downward into the sand were short and distorted, whereas those that pointed upward into the loamy soil were long and intricately branched.

Four ranks of roots were found in garden *K*, but elsewhere (gardens *C* and *Q*), a fifth and smaller (or lower) rank was detected (fig. 30, *F, G, H*). In structure, each rank resembled the others. Except for the primary roots which were attached to the trunk, all the roots arose from the pericycle of the next older root. The quaternary and quintary roots, though small, were multicellular and contained a vascular cylinder within an epidermis, tegumentary system, and cortex. No root hairs were observed.

The vertical distribution of date roots varies apparently in relation to such factors as soil texture, moisture, aeration, and fertility. It is generally observed that, in well-drained soil and at a little distance from the trunk, roots do not inhabit soil in the first-foot layer. A few roots may penetrate very deeply. Most of the roots, however, spread outward in soil between 1 and 6 feet in depth and permeate those regions where environmental conditions are most favorable. In

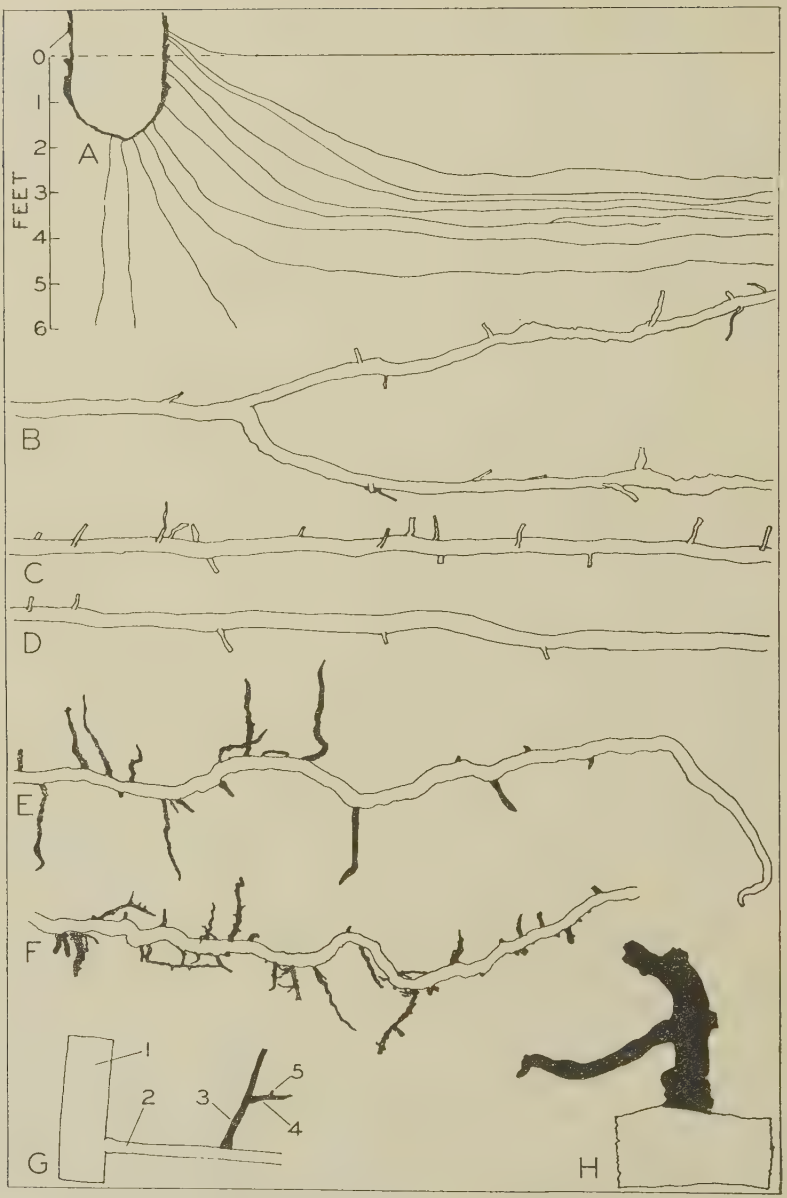


Fig. 30.—Root system of a Deglet Noor date palm: *A*, vertical section through the root zone of the trunk and through the soil, indicating the distribution of primary roots; *B*, *C*, and *D*, outline drawings of consecutive segments of a primary root which was taken at a distance of 20 feet from the trunk (× 0.24); *E*, secondary root (× 0.71); *F*, tertiary root (× 0.95); *G*, diagram indicating the five ranks of roots: (1) primary, (2) secondary, (3) tertiary, (4) quaternary, and (5) quintary; *H*, quaternary and quintary roots (black) attached to a tertiary root (× 10.7).

the Coachella Valley the soils are so variable and stratified that the vertical distribution of roots on opposite sides of the same palm may sometimes be noticeably different.

Studies were also made of the location of the causal fungi in the roots of the palm. A severely affected Deglet Noor palm in garden *Q* was selected. This twelve-year-old palm had 11 green leaves, and the trunk stood 4 feet high at the fiber line. A deep trench was dug so that one side formed a vertical plane tangent to the trunk. On this side of the trench and beginning at a point where the soil surface touched the trunk (fig. 31), series of 1-foot squares were

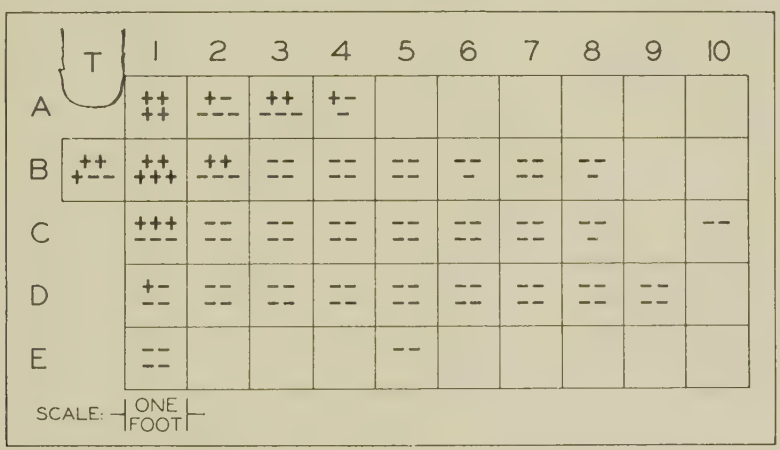


Fig. 31.—Diagram showing the vertical and lateral distribution of *Omphalia tralucida* in the root system of a twelve-year-old Deglet Noor palm as indicated by tissue cultures from the root segments found in 51 different cubic feet of soil. Root segments from which *O. tralucida* were cultured are indicated with a plus sign (+); those from which it was not cultured are indicated with a negative sign (−). There were no date roots in the soil represented by the blank squares. T = trunk of the palm; the numbers indicate the vertical rows of earthen cubes; the letters, the horizontal rows.

marked for a distance of 10 or 11 feet laterally and to 5 feet in depth. The cubic foot of soil behind each of 51 squares that had been marked on the wall of the trench was then excavated separately and screened to separate the roots. The cubes of soil near the base of the trunk contained many roots, whereas those at greater radius or depth contained only a few or none. From the base of the trunk, 6 inches below the surface, a few living roots extended downward into the soil. About 95 per cent of the roots were necrotic and in different stages of decomposition. The presence of viable mycelium of omphalia was tested in tissue cultures made from the segments of primary roots excavated. Only 33 of the 51 cubes of earth contained such roots. Each culture represented a different root segment, though different segments of the same root may have been cultured in 2 or more samples.

Omphalia tralucida was isolated from only 9 of the 33 samples (fig. 31). All positive results were from samples which had been taken within 4 feet of the trunk and mostly where root concentration was high. In the surface foot (row *A*) omphalia was cultured from 4 consecutive samples. Row *B* yielded the pathogen from the sample immediately beneath the trunk and also from

the 2 adjacent samples. Other positive results were obtained from samples *C1* and *D1*.

Although omphalia was not detected beyond a radius of 4 feet, various other soil fungi were encountered, *Fusarium* spp. being the most common. Very few mixtures occurred in cultures, especially between omphalia and fusarium. This might indicate that fusarium follows omphalia and destroys the latter in roots of diseased palms. Fusarium does not, however, prevent attack by omphalia on healthy palms. Three cultures, representing different types of *Fusarium* from this experiment, were inoculated singly and in combination with *Omphalia tralucida* in soil about potted Deglet Noor seedlings. Whereas the cultures of fusarium produced no visible effect, those of fusarium plus omphalia not only produced the typical lesions of omphalia root rot but caused approximately as much injury as did omphalia alone.

The condition of the diseased palm from which these root samples were taken, is not necessarily typical of that of all diseased palms. It represents only one of several stages through which the palm had passed during the previous twelve years. Whether mycelium of omphalia had penetrated at any time to the tips of the necrotic roots is not known. Certainly, a primary root tip from another palm encountered in sample *D8* (fig. 31) was healthy and apparently well removed from the nearest viable mycelium of omphalia. The results of this experiment indicated the region where omphalia was most concentrated, but they did not show how the disease may be spread to adjoining palms.

In garden *K* a trench was dug between 2 Deglet Noor palms diagonally across a 30-foot tree square, and special attention was given to the distribution of omphalia in the roots. The trench was divided into eight 5-foot sections, and most of the roots taken to a depth of 5 feet were sorted in piles, one for each section. The palm at one end of the trench was diseased (fig. 11, *B*), and the other one appeared healthy (fig. 11, *C*). Although many dead roots were encountered, the disease had not advanced so far as in the palm previously described (p. 77). Necrotic secondary roots were common. Sometimes necrosis extended only to the junction with the primary root. There were instances where a dead root touched a living root in the soil, but examination of the latter at the point of contact failed to show necrotic lesions.

Measuring from the diseased palm (fig. 11, *B*), *Omphalia tralucida* was cultured from 3 roots at a distance of 3 to 4 feet, and from one long root, at 12 and 20 feet, respectively. Tissue plantings on culture medium had been made from roots taken at 1-foot intervals from 9 to 22 feet. Inner tissues of the root were white within 1 foot of the distal end, but those in the remaining portions varied in color from off-white to yellowish or brownish. The microflora of the discolored zone varied considerably. Tissue plantings from different places yielded bacteria, *Rhizoctonia* sp., *O. tralucida,* and an unidentified sterile fungus. One planting remained sterile. In this root omphalia seemed to be localized in certain zones, and the intervening regions of devitalized or necrotic tissues contained only nonparasitic organisms. These results are significant, however, because these isolations of omphalia were taken at points farther out on the roots than in previous tests.

Another long necrotic root segment was taken from the trench, but this one was connected to the healthy palm (fig. 11, *C*). Other necrotic roots were in

close proximity to this root at one place. Isolations failed to detect omphalia at any point along the 16-foot segment, and the cause of its death was unknown. The tissue plantings either remained sterile or yielded *Rhizoctonia* sp., *Trichoderma lignorum* (Tode) Harz, *Penicillium* sp., an unidentified sterile fungus, or bacteria.

Rhizomorphs of omphalia were demonstrated on the surface of date roots of three-year-old seedlings in the field 5 months after inoculation (plate 4, *A, B*). Where liberal amounts of agar and bran inoculum had been used, the rhizomorphs grew along certain roots for 75 cm. Rhizomorphs have since been found between the leaf bases of diseased palms (fig. 2, *B*) and also on roots that were infected naturally. It is not likely, however, that the pathogen spreads altogether by means of rhizomorphs.

The migration of *Omphalia pigmentata* and *O. tralucida* through soil was studied in the greenhouse in two large galvanized iron containers, 183 cm long, 35 cm wide, and 38 cm deep. Filled with fine sandy loam and provided with holes for drainage, each container was planted with Deglet Noor seedlings in 11 rows and 9 seedlings per row. Two 5-gallon containers each with 9 seedlings served as controls. Sections of lath, 35 cm long, were placed on edge in the soil between the rows of seedlings to prevent water from washing over the surface. Inoculations were made first when the plants were 3 months old. Whereas each control received 80 ml of sterile bran, the soil about the plants in row no. 1 of each large container received 480 ml of infested bran. By concentrating all of the inoculum at one end of the container, it was possible to measure the rate and extent of spread by taking up some of the plants after different intervals of time.

Disease symptoms first appeared after 6 days, but the disease did not spread beyond the first row. A second application of 480 ml of infested bran was given after 293 days and after two thirds of the plants had been thinned out, this time to the first 3 rows. Half of the remaining plants were examined after 466 days and all were examined 700 days after the first inoculation. Whereas nearly all plants in contact with the fungus-covered bran had developed lesions of omphalia root rot, no evidence of fungus migration was found. There had been many interlocking roots at the time of the second inoculation and soil temperatures had ranged between 14° and 31° C. All factors had seemed favorable to the development of disease except the possible resistance of the seedling date palms. This factor had been observed previously and was known to increase as the palms grew older.

Creation of New Foci of Disease.—From the evidence at hand, the spread of omphalia root rot from tree to tree in the orchard is not well understood. Better understanding is had, however, of the creation of new foci of disease. The disease appears to be spread entirely by means of the fungus mycelium, since spores are not usually formed under natural conditions. *Omphalia pigmentata* was once taken from a detached leaf base in soil. This leaf might possibly have spread infection had it been carried to noninfested soil, but no case of this kind has been reported. The principal means of spread appears to be that of transplanting infected palms or their offshoots.

In 1928 before the cause of omphalia root rot was known, a badly affected palm in garden *V* was transplanted intentionally to another part of the or-

chard to test the possibility of transmitting the disease from place to place. The results were positive. The palm had not recovered after five years, and much evidence of *Omphalia tralucida* was found in the roots. In conjunction with this test, the owner cut 22 offshoots from diseased, and 34 offshoots from healthy Deglet Noor palms, and planted them in adjoining rows at some distance from the affected area. The growth rate of the two lots was not the same. After five years the average volume in the tops of those palms derived from healthy parents was nearly six times greater than that in palms whose parents were diseased (see data on p. 59). Furthermore, the secondary symptoms of omphalia root rot had appeared in nearly all members of the latter group, whereas those of the first group were healthy. *O. tralucida* was found only in palms that had come from diseased parents.

It has been mentioned already (p. 19) that offshoots from diseased palms are often infected (fig. 2). Offshoots arising from the root zone are subject to attack, and when separated from the parent, may show slight to severe primary symptoms. Other offshoots that develop entirely above the soil line are less apt to become infected because omphalia cannot withstand the usual desiccating effect of the air.

As a rule, only healthy-appearing offshoots are used for propagation. If infected when planted, such palms may develop for several years before showing the secondary symptoms of disease. Much difficulty was experienced when an attempt was made to establish a new planting with offshoots from garden *N*, where omphalia root rot was already known in two areas. One of the dying offshoots was examined 2 or 3 months from the time of transplanting and was found to be badly infected with *Omphalia tralucida*. Although the exact parentage of the offshoot was unknown, it had apparently been taken from one of the older diseased palms.

The spread of disease by means of infected offshoots has contributed to a serious situation in garden *Q*. Offshoots from the original planting of Deglet Noor palms were propagated in two younger blocks in 1923 and 1928, respectively. Records taken by the owner indicate that in May, 1928, 68 out of 217 palms in the original planting showed symptoms of disease. Presumably omphalia had been established in this orchard for several years before this time. In the 1923 planting (fig. 32), the symptoms of omphalia root rot appeared about 1930. Surveys at various intervals indicated that in 1931 there were 8 affected palms; in 1934, 33 affected palms, and in 1937, 66. Since the symptoms appeared almost simultaneously in different parts of the block, it seems likely that a number of foci of disease had been established by planting several infected offshoots. Omphalia root rot also appeared in the 1928 planting and subsequently caused considerable loss.

Diseased offshoots from garden *Q* are also suspected of spreading omphalia root rot to garden *Z* where, a few years later, other offshoots were cut for propagation in garden *O*. The disease is now evident in all 3 gardens.

A similar series of events has been reconstructed in the case of five different plantings in the Oasis district (fig. 33). Deglet Noor offshoots, imported from French North Africa in 1914, were planted in a nursery at garden *V*. Some of these offshoots were transplanted in 1915 to garden *U* and, in 1924, offshoots from these palms were taken for orchard planting in garden *W*. In 1916 the

owner of garden *V* used the remaining offshoots from the nursery to plant his own orchard. Two younger plantings (one of which was mentioned on p. 59) were made in garden *V* from offshoots of the original planting. Omphalia root rot has been identified in all five of these orchards which traced directly to offshoots imported in 1914.

The original orchard in garden *G* was planted in 1915 with imported offshoots. At least three new foci of infection have since been discovered in other blocks of palms that originated as offshoots from the first planting.

Palms in garden *L* were obtained from a nursery at Yuma, Arizona, and

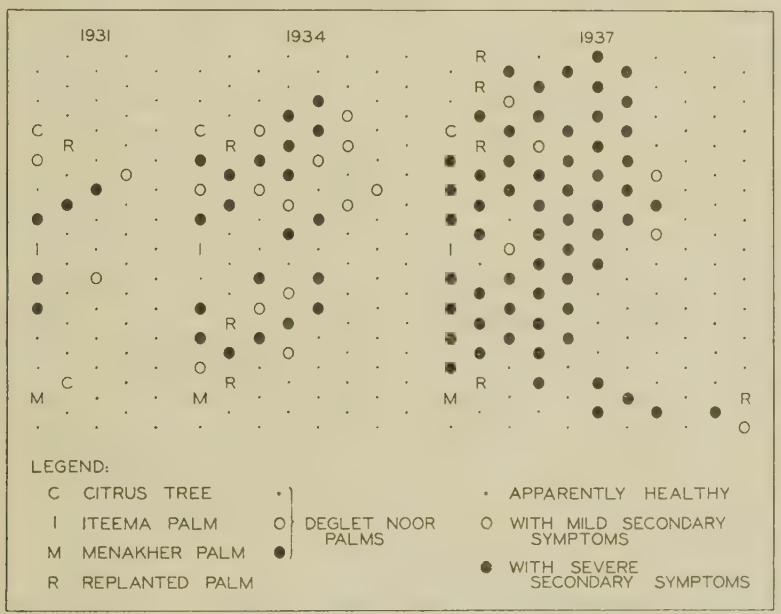


Fig. 32.—Three maps of an omphalia-root-rot area in garden *Q*, indicating the visible spread of the disease between 1931 and 1937.

planted in an orchard between Thermal and Mecca. Because of unfavorable soil conditions, the palms were transplanted about 1927 to their present location near Indio. Five years later the symptoms of omphalia root rot were evident in palms at several places within this orchard. Although direct evidence is lacking, it may be conjectured that at one time some of the affected palms had been situated in a group where all had become infected. The arrangement of the palms was changed during the transplanting operation; and the diseased palms were scattered among the healthy ones and thus created several new foci of disease.

Infection of Replanted Palms.—Where the pits of fallen date fruits germinate near diseased palms, the seedlings are sometimes attacked. Such was true in garden *B* after the removal of a large diseased palm (fig. 21). Detached segments of infected roots had been left in the soil near the surface where the seedlings were growing.

In garden *T*, where no soil disinfectants had been used, several healthy off-

shoots of Deglet Noor variety were replanted in spaces where diseased palms had been removed. These young palms became severely stunted and, after five years, showed much evidence of omphalia root rot. Similar results were obtained with palms in untreated (control) areas of soil-disinfection experiments in gardens *C* and *V* (see p. 106–7).

An extensive replanting experiment has been conducted since 1933 in gardens *I* and *T*. Starting with 50 healthy Deglet Noor offshoots from a nursery at garden *I*, and 50 supposedly healthy Khadrawy offshoots from a nursery in garden *T*, 10 offshoots of each variety were planted in a healthy area in

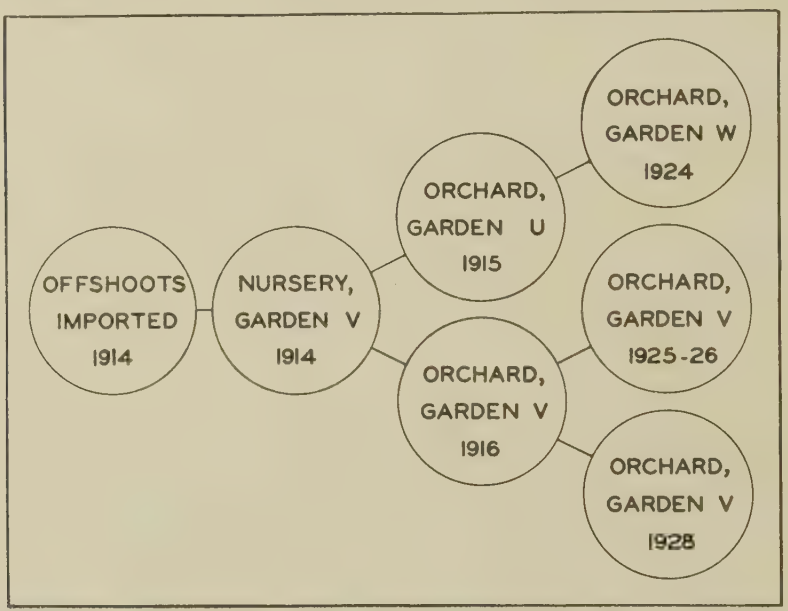


Fig. 33.—The spread of omphalia root rot on offshoots to five Deglet Noor orchards in gardens *U*, *V*, and *W*. The parent palms were imported as offshoots from French North Africa in 1914.

garden *I*, 20 offshoots of each variety were planted in a healthy area in garden *T*, and 20 offshoots of each variety were interplanted between rows of diseased palms in garden *T*. By using equal numbers of Deglet Noor and Khadrawy palms, a controlled experiment was thus initiated to study the infection of replanted palms. The old affected palms in the diseased area of garden *T* were destroyed in 1936; this left the young, replanted palms in regular orchard spacing and without further competition from the older palms. To promote vegetative growth, applications of ammonium sulfate (3¾ to 5 pounds per palm) were made in 1937 and in each year thereafter to all the palms in this experiment.

Measurements of trunk height were taken for the purpose of comparing the mean growth rate of palms in the different plots of this experiment. The comparative growth measurements were based on the size of the palms in May, 1935, and they indicate that the growth rate of Deglet Noor palms in the dis-

eased area of garden *T* was noticeably reduced after 1938, while that of the other Deglet Noor palms in the healthy (control) areas increased (fig. 34). The growth rate of the Khadrawy palms was much slower than that of the Deglet Noor palms. Although the growth rate of Khadrawy palms in the diseased area lagged somewhat behind that of Khadrawy palms in the healthy areas, the differences were not pronounced. Secondary symptoms of omphalia root rot appeared in 1938 in 4 of the Deglet Noor palms in the diseased area. The number of visibly affected palms in this plot increased steadily. In 1941, 16 out of 20 Deglet Noor palms in the diseased plot showed definite symptoms of dis-

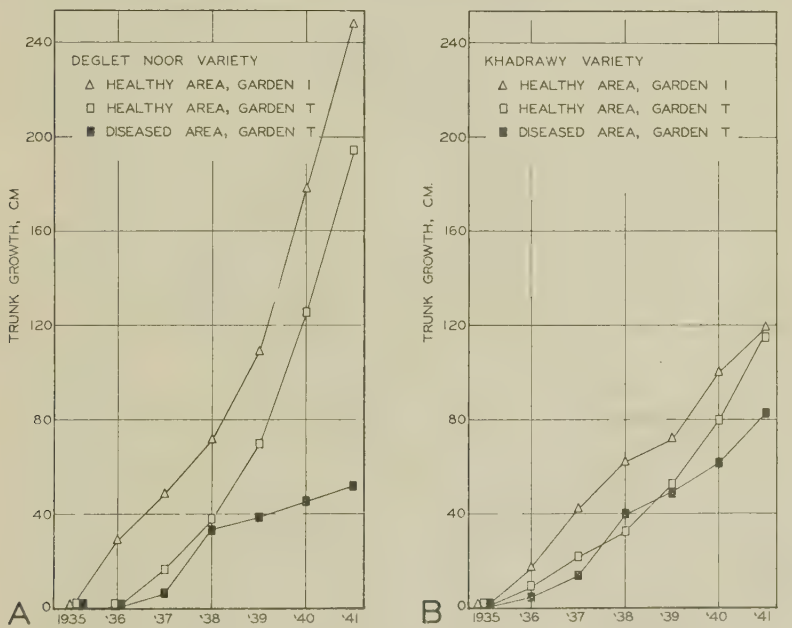


Fig. 34.—Mean rate of trunk growth of palms planted in healthy and diseased soil in gardens *I* and *T* over a period of six years: *A*, Deglet Noor variety; *B*, Khadrawy variety.

ease, but up to that time none of the control plants had shown any symptoms (fig. 35). Palms of the Khadrawy variety were not visibly affected in any of the plantings (fig. 36).

Beginning in 1939, the isolation of fungi from root samples of the weaker palms revealed the presence of *Omphalia tralucida* in both the Deglet Noor and Khadrawy varieties within the diseased area of garden *T*, and in the Khadrawy variety in the healthy (control) areas of garden *I* and *T*. One Khadrawy palm in garden *I* yielded *O. pigmentata*. None of the Deglet Noor palms in the healthy (control) areas were found to be infected. The cultures of *Omphalia* spp. which were isolated from the palms in this experiment were found to be highly pathogenic on potted seedlings of Deglet Noor date palm in the greenhouse.

The results of this experiment are thought to be rather significant. There is evidence that some of the Khadrawy offshoots from the nursery in garden *T*

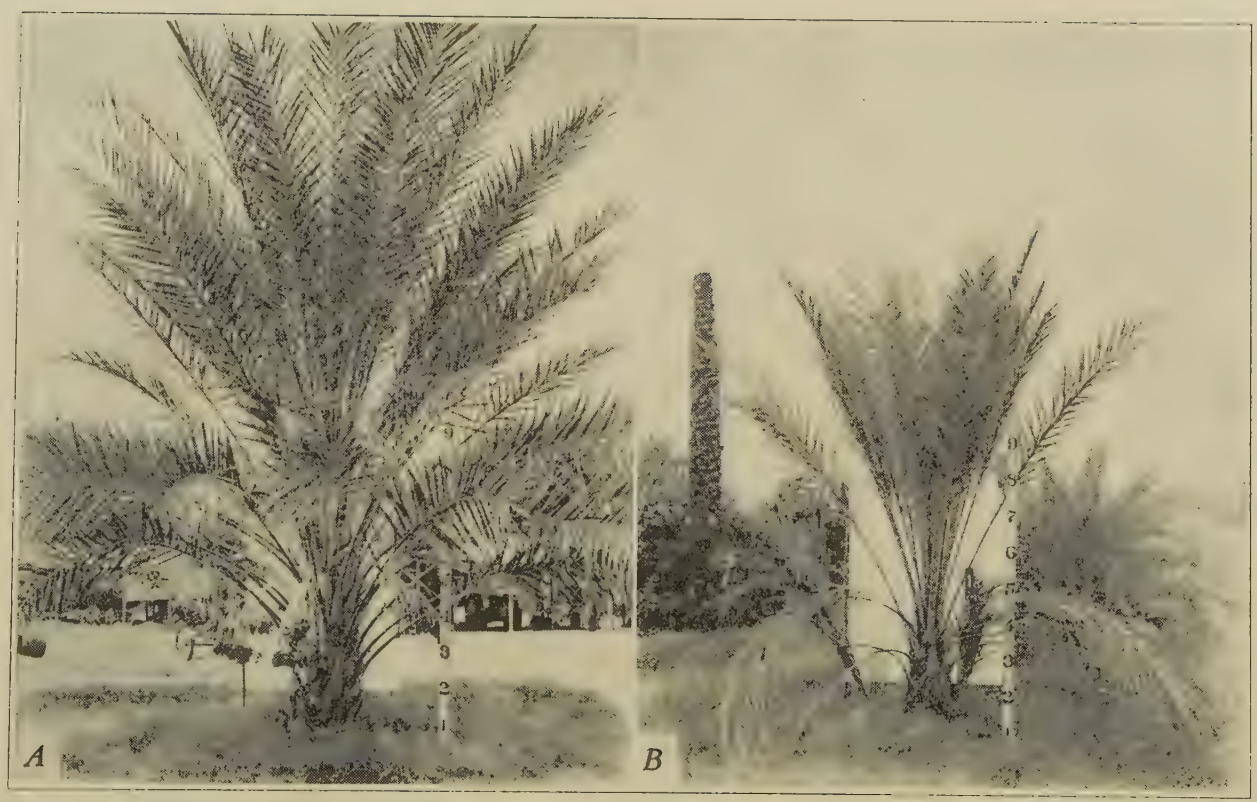


Fig. 35.—Deglet Noor date palms, eight years of age: *A*, planted in noninfested soil (control); *B*, planted in an omphalia-root-rot area.

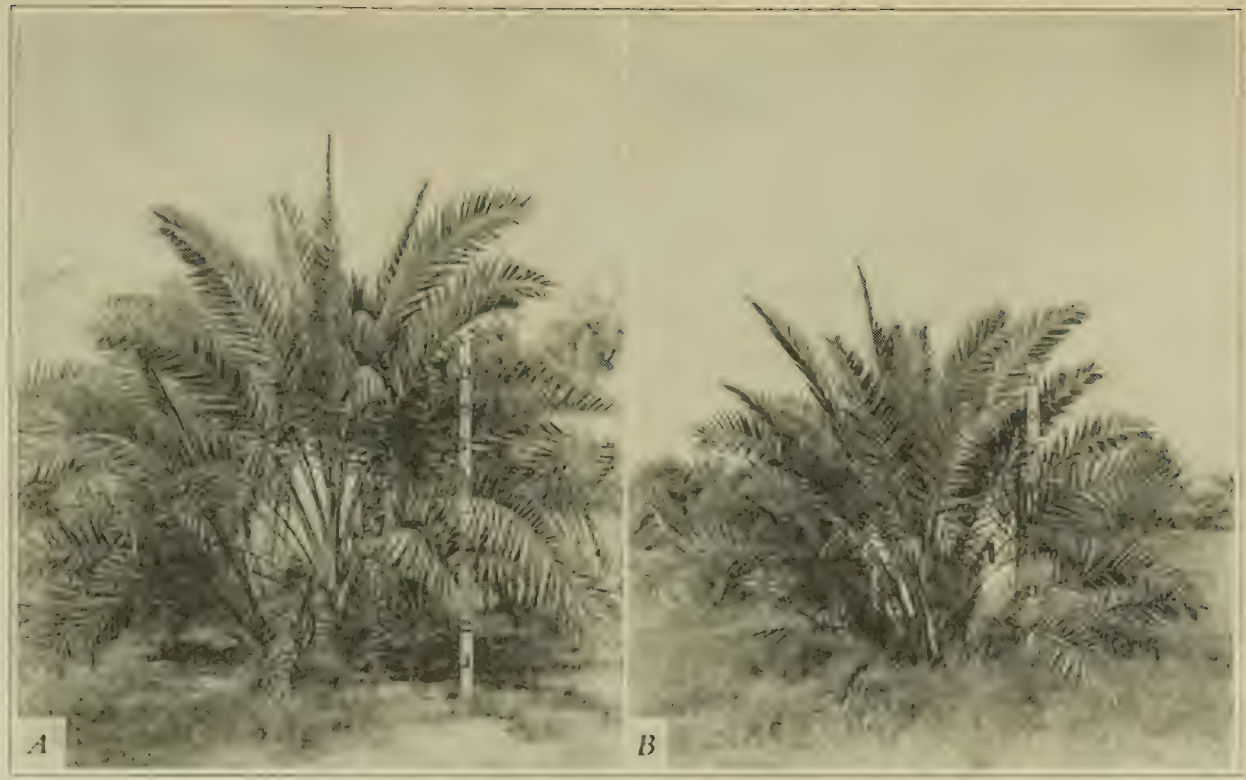


Fig. 36.—Khadrawy date palms, eight years of age: *A*, planted in noninfested soil (control); *B*, planted in an euphalia-root-rot area.

were infected with omphalia at the beginning of the experiment. Apparently, the Deglet Noor offshoots from garden *I* were originally healthy, since only those that were planted in infested soil developed symptoms of disease. Although 6 Khadrawy palms are known to be infected, the tops of these palms have remained green, and, with the exception of 2 palms, the growth rate has been satisfactory. The mycelium of omphalia in these Khadrawy palms was found between the leaf bases and, to some extent, in lesions on the roots. The extent of injury, however, was slight. The presence of typical primary and secondary symptoms in 16 out of 20 of the Deglet Noor palms in the diseased area of garden *T*, and the total absence of disease symptoms in the control palms of this variety, indicate that healthy Deglet Noor offshoots cannot be replanted successfully in soil where omphalia occurs. The latent period for the disease in young Deglet Noor palms is about five years. It is not known whether palms of the Khadrawy variety ever become noticeably affected. So far as this experiment has gone, the Khadrawy palms, both inside and outside of the diseased area, have made a reasonably satisfactory development considering the cultural conditions under which they have grown. Under these environmental conditions where the Deglet Noor variety is worthless because of omphalia root rot, palms of the Khadrawy variety have shown little effect. There is already some indication that the Khadrawy variety can be replanted in areas where omphalia root rot is known and especially where soil disinfection is not practicable.

Differences among date varieties in the expression of the secondary symptoms of omphalia root rot are attributed to differences in susceptibility. Whereas the reactions of Deglet Noor palms to the pathogen may include severe stunting in addition to root necrosis, the reactions of Khadrawy palms may include only root necrosis causing minor injury. Both varieties may be infected but to different degrees. The reason for these differences in varietal susceptibility has not been explained.

CONTROL

With omphalia root rot, the most promising methods of control deal with prevention and eradication. Treatment, at the present time, is not well understood.

PREVENTION

It may be concluded from the preceding pages that omphalia spreads from place to place mostly on diseased palms or their offshoots; that when omphalia is established in the soil the disease tends to spread outward in ever-widening circles; and that healthy palms, when planted in infested soil, are apt to become diseased. Furthermore, there is circumstantial evidence that soils in the Coachella Valley were not originally infested with omphalia but that certain areas have become infested during recent years because of the introduction of the disease. If these conclusions are correct, it follows that the occurrence of omphalia root rot may be prevented in this region by using only healthy offshoots in noninfested soil. This appears to be the most important and the most practical method for the control of omphalia root rot.

Differences in varietal susceptibility have been observed both in naturally and in artificially inoculated palms. Surveys of diseased areas, extending over

a period of ten years, have given observational evidence that Khadrawy, Halawy, Iteema, Tazizaoot, Khustawy, Zahidi, and Tafazwin varieties possess considerable tolerance of the disease, since none have been affected noticeably.



Fig. 37. Vigorous seedling date palm (left foreground) completely surrounded by diseased palms of Deglet Noor variety. These palms were imported as offshoots from French North Africa in 1915 and had developed for twenty-two years under uniform environmental conditions.

It should be remembered, however, that the mycelium of omphalia has been isolated from each of these varieties and that all, though tolerant, are somewhat susceptible to attack.

Since the horticultural varieties of date palms are clones and carry the same

genetic characters as the seedling palms from which they were propagated, as much difference in relative susceptibility probably occurs among seedlings as among varieties. Seven of the 30 mature seedling palms in the original omphalia-root-rot area of garden *Q* show secondary symptoms of disease in different degrees of severity, but 23 are apparently healthy and some are

TABLE 12

RELATIVE VIRULENCE OF DIFFERENT CULTURES OF *Omphalia pigmentata* AND *O. tralucida* ON SEEDLINGS OF DEGLET NOOR DATE PALM IN THE PERIOD BETWEEN 21 AND 36 MONTHS OF AGE

Omphalia pigmentata		*Omphalia tralucida*		Control	
Culture and inoculation no.	Infection*	Culture and inoculation no.	Infection*	Inoculation no.	Infection*
Culture 1803		Culture B-33			
781	+ +	782	−	780	−
797	++	798	−	785	−
813	+++	Culture B-184		790	−
Culture B-152		786	+?	795	−
783	+++	802	−	800	−
799	+++	Culture B-196		805	−
Culture B-182		787		810	−
784	++	803	−	815	−
801	++++	Culture B-206			
Culture B-301		788	−		
794	+	804	−		
811	+++	Culture B-207			
814	+++	789	−		
		806	−		
		816	−		
		Culture B-271			
		791	−		
		807	−		
		819	++		
		Culture B-287			
		792	−		
		808	+		
		818	−		
		Culture B-298			
		793	+?		
		809			
		817			
		Culture B-304			
		820	−		
		821	−		
		Culture B-318			
		796	−		
		812	−		

* Infection: − = none; + = slight; ++ = moderate; +++ = severe; and ++++ = very severe

remarkably vigorous although they are surrounded by diseased Deglet Noor palms (fig. 37). Because of their age and physiological condition, it is no longer possible to propagate vegetatively these disease-resistant palms. The situation in garden *Q* is suggestive, however, of a method for selecting resistant seedlings that might be propagated as horticultural varieties.

Whereas most seedling date palms less than one year of age are highly susceptible to infection by *Omphalia* spp., older seedlings develop considerable resistance. That older seedlings may develop more resistance to *O. tralucida*

than to *O. pigmentata* is indicated by a series of inoculations on seedlings of Deglet Noor date palm, 21 months of age (table 12). These plants, which were grown singly in 5-gallon-can containers, were inoculated either in duplicate or in triplicate with 4 isolates of *O. pigmentata* and 10 isolates of *O. tralucida.* After 15 months all the palms inoculated with *O. pigmentata* showed infection and most of them were severely affected. Of the 24 palms inoculated with *O. tralucida,* only 4 showed any signs of infection. The control plants were healthy. The results of this experiment are unique because at no other time during this investigation has there been observed such a marked difference in the pathogenicity of the two species.

Two inoculation experiments have been conducted in the Coachella Valley on rooted date offshoots (p. 42–47). These experiments were organized for the purpose of comparing the relative susceptibility of the horticultural varieties that are now grown most commonly in the Coachella Valley.

In the first experiment with *Omphalia tralucida,* palms of the Khustawy and Zahidi varieties appeared to be more resistant than those of Deglet Noor variety. The second experiment, though not completed, demonstrated that necrotic lesions may be found in the roots of at least 18 different varieties.

TREATMENT

Early attempts to control omphalia root rot by means of chemicals were not successful (p. 30–34). Although in 1931 Haas and Klotz (*29*) had reported indications of growth stimulation and recovery in a diseased palm of Deglet Noor variety after the application of 50 pounds of copper sulfate to the soil, later treatments of this kind gave negative results. Preliminary experiments (*7*) with potted date seedlings also indicated that soil treatment with copper sulfate did not prevent or control infection by omphalia. In one experiment, soil treatments with relatively large amounts of copper sulfate, aluminum sulfate, oxalic acid, and potassium nitrate with tricalcium phosphate seemed to increase the percentage of infected seedling plants.

Because toxicity of ammonia to *Phymatotrichum omnivorum* (Shear) Duggar was reported by Neal, Wester, and Gunn (*44*) and because partial control of the root rot caused by this organism (*32, 34, 48, 49*) was obtained with various nitrogenous fertilizers, attention was turned to the possibility of controlling omphalia root rot by similar methods.

In May, 1935 (experiment no. 1), a uniform lot of Deglet Noor seedlings was inoculated partly with bran infested with *Omphalia tralucida* (culture B–181) and partly with sterile bran (controls). These seedlings were 4 months old and were growing in fine sandy loam in 5-gallon containers. Beginning 2 days after inoculation, weighed amounts of dry salts of ammonium, potassium, calcium, and sodium were spread over the surface of the soil in 3 equal amounts at 7-day intervals. Irrigation with tap water served to dissolve the salts and carry them into the soil. Readings on the pH of the soil in the upper 1-centimeter layer were taken 2 days after the final application of chemicals and again at the end of the experiment, 6 months later. At first the soil was acidified by ammonium sulfate and tricalcium phosphate, but at the end of the period all readings were at the level of pH 7.8 or above. The results of experiment no. 1 (table 13) were measured both by plant growth and by root-rot development.

TABLE 13

EFFECT OF CHEMICAL SOIL TREATMENTS ON OMPHALIA ROOT ROT AND ON GROWTH OF SEEDLING DEGLET NOOR DATE PALMS, EXPERIMENT NO. 1, MAY TO NOVEMBER, 1935

Inoculum, treatment, and amount per square foot*	Plants inoculated			Average per living plant					Aborted roots†
	Total	Diseased	Dead	Diameter basal node	Length longest leaf	Green leaves	Primary roots		
							Healthy	Aborted	
	number	*number*	*number*	*mm*	*cm*	*number*	*number*	*number*	*percent*
Water only									
Control	9	0	0	19.8	61	7.7	6.0	0.0	0
	4	0	0	22.0	51	8.5	8.0	0.0	0
Omphalia tralucida	9	8	0	21.0	41	6.2	4.7	1.9	29
	9	9	2	21.9	42	7.4	4.7	1.9	44
Ammonium sulfate									
11.3 grams									
Control	9	0	0	22.0	71	8.2	7.0	0.0	0
O. tralucida	9	8	1	24.0	69	8.4	5.9	1.8	31
45.3 grams									
Control	6	0	0	23.4	49	9.0	7.2	0.0	0
O. tralucida	9	5	1	25.0	51	8.4	7.4	0.6	18
90.7 grams									
Control	9	0	0	19.6	51	8.0	6.4	0.0	0
O. tralucida	9	6	0	20.7	49	8.2	6.3	0.2	3
181.3 grams									
Control	9	0	0	17.9	47	7.1	6.1	0.0	0
O. tralucida	9	5	0	19.8	59	7.9	5.3	0.7	12
Potassium nitrate									
113.5 grams									
Control	6	0	0	22.8	52	8.3	7.5	0.0	0
O. tralucida	9	5	0	20.2	60	7.9	6.8	0.3	4
Tricalcium phosphate									
113.5 grams									
Control	8	0	0	22.9	56	7.8	7.5	0.0	0
O. tralucida	8	8	5	23.3	45	7.0	5.7	1.3	61
Potassium nitrate 113.5 grams and tricalcium phosphate 113.5 grams									
Control	8	0	0	23.5	64	8.0	8.4	0.0	0
O. tralucida	9	9	3	21.2	54	6.2	5.3	0.5	39
Sodium chloride									
28.4 grams									
Control	9	0	0	20.6	55	8.5	6.6	0.0	0
O. tralucida	7	7	2	21.6	70	7.4	4.8	2.4	53
113.5 grams									
Control	8	0	0	16.9	38	6.4	5.8	0.0	0
O. tralucida	7	7	3	17.7	39	3.8	3.0	1.8	65
Calcium nitrate									
81.1 grams									
Control	8	0	0	23.5	55	9.4	8.4	0.0	0
O. tralucida	9	8	3	22.1	56	7.3	5.8	1.3	47

* Chemicals applied in 3 equal amounts at 7-day intervals beginning 2 days after inoculation.
† Percentage weighted to include dead plants which are assumed to have the same average number of roots as the living plants.

Judging from the size and condition of the plants that were alive at the end of the experiment, the nitrogenous fertilizers, except for ammonium sulfate in the two largest applications, increased the growth rate.

Treatments of ammonium sulfate and potassium nitrate reduced the incidence of disease and those with tricalcium phosphate and sodium chloride increased it.

Since the abortion of roots was considered to be the most damaging effect of omphalia, the relative severity of attack was indicated by the percentage of aborted roots in each lot of plants. These percentages were weighted to include the roots of the dead plants which were assumed to have had the same average number of roots as the living plants. The treatments with ammonium sulfate (90.7 grams per sq. ft.) and potassium nitrate (113.5 grams per sq. ft.) had been most effective in preventing root rot. Whereas inoculated but untreated plants had 29 to 44 per cent of the roots aborted, those treated with tricalcium phosphate (113.5 grams per sq. ft.) had 61 per cent, and those with sodium chloride (113.5 grams per sq. ft.) had 65 per cent. The treatments with calcium nitrate and with 45.3 grams of ammonium sulfate had equivalent amounts of nitrogen. Root abortion in the first was 47 per cent and that in the second was only 18 per cent.

The rate of disease development was also noticeably increased by certain treatments. Within 18 days from the time of inoculation (results not shown in table 13) 100 per cent of the plants with tricalcium phosphate alone and with sodium chloride (113.5 grams per sq. ft.) showed symptoms of disease. After the same interval, only 44 per cent of the inoculated but untreated plants were affected.

When potassium nitrate, which seemed to check the disease, and tricalcium phosphate, which seemed to increase it, were applied in combination, they had no effect on the rate or on the extent of disease development, apparently counteracting each other's effect.

Because of the results in experiment no. 1, it seemed desirable to investigate more fully the effect of various chemicals on plant growth and on the development of disease. Experiment no. 2 was conducted with 17 chemicals which represented the hydroxides, nitrates, sulfates, and phosphates of hydrogen, potassium, ammonium, and calcium. Seedlings of Deglet Noor date palm were grown in 5-gallon containers in soil of light sandy loam. When 6 months of age, the seedlings were inoculated partly with *Omphalia tralucida* (culture B–181) and partly with sterile bran (controls). The chemicals for soil treatment were dissolved in water and applied in 3 equal amounts at 7-day intervals, beginning 2 days after inoculation. Three of the calcium salts were applied in a mixture of white sand because they were not soluble. The application of chemicals was based on the amount of ammonium sulfate which, judging from experiment no. 1, was thought to be most effective in checking the disease, but at the same time was reasonably favorable to plant growth. Since this amount of ammonium sulfate (68 grams per sq. ft., or 60 pounds per 400 sq. ft.) supplied 10.35 grams of nitrogen per square foot, the amounts of all other nitrogenous compounds were calculated to supply nitrogen in equivalent amounts. Likewise, all potassium compounds supplied amounts of potassium equivalent to that in potassium nitrate; and all calcium compounds supplied amounts of calcium equivalent to that in calcium nitrate. The sulfur in sulfuric acid was equivalent to that in potassium sulfate, and the phosphorus in orthophosphoric acid was equivalent to that in potassium monohydrogen phosphate.

The pH of the top soil (0 to 1-inch depth) was measured by the quinhydrone method (*30*) 14 days after the time of inoculation and again at the conclusion of the experiment, 10 months later. Whereas the pH of the soil in different

TABLE 14

EFFECT OF CHEMICAL SOIL TREATMENTS ON OMPHALIA ROOT ROT AND ON GROWTH OF SEEDLING DEGLET NOOR DATE PALMS, EXPERIMENT NO. 2, FEBRUARY TO DECEMBER, 1936

Treatment (formula), inoculum, and amount per square foot*	Plants inoculated			Average per living plant					Aborted roots†
	Total	Diseased	Dead	Diameter basal node	Length longest leaf	Green leaves	Primary roots		
							Healthy	Aborted	
	number	*number*	*number*	*mm*	*cm*	*number*	*number*	*number*	*percent*
Water only, H_2O									
Control	8	0	0	24.8	56.4	7.9	6.1	0.0	0
	8	0	0	24.5	57.0	6.9	5.8	0.0	0
	9	0	0	22.4	62.2	7.3	5.9	0.0	0
Omphalia tralucida	9	9	1	23.7	49.4	7.8	6.0	0.5	18
	8	8	2	26.1	58.0	7.5	6.3	1.0	35
	9	9	1	24.5	56.0	6.4	6.1	0.6	19
Nitric acid, HNO_3, 65.1 ml									
Control	9	0	0	32.4	83.6	8.2	8.7	0.0	0
O. tralucida	9	9	0	27.0	73.3	7.3	7.2	0.2	3
Sulfuric acid, H_2SO_4, 29.0 ml									
Control	9	0	0	21.2	65.4	6.8	5.4	0.0	0
O. tralucida	9	7	0	29.5	69.1	8.3	7.6	0.4	6
Orthophosphoric acid, H_3PO_4, 34.8 ml									
Control	9	0	0	25.0	62.1	7.7	6.1	0.0	0
O. tralucida	9	8	5	26.9	81.2	7.3	8.0	0.0	56
Potassium hydroxide, KOH, 58.6 grams									
Control	9	0	0	21.7	69.8	6.8	6.1	0.0	0
O. tralucida	9	3	0	22.2	57.6	7.9	5.8	0.0	0
Potassium nitrate, KNO_3, 103.2 grams									
Control	9	0	0	23.5	79.3	6.2	6.9	0.0	0
O. tralucida	9	9	2	21.7	66.4	6.3	5.7	0.6	29
Potassium sulfate, K_2SO_4, 90.0 grams									
Control	9	0	0	23.5	77.3	7.3	6.6	0.0	0
O. tralucida	9	9	3	29.1	64.2	8.2	7.0	0.3	36
Potassium monohydrogen phosphate, K_2HPO_4, 90.0 grams									
Control	9	0	0	28.7	77.4	8.0	7.7	0.0	0
O. tralucida	9	9	0	22.8	72.0	7.1	5.9	0.8	12
Ammonium hydroxide, NH_4OH, 67.8 ml									
Control	9	0	2‡	21.9	79.0	6.4	6.3	0.0	0
O. tralucida	9	0	2‡	27.7	70.6	7.6	7.0	0.0	0
Ammonium nitrate, NH_4NO_3, 40.7 grams									
Control	9	0	0	26.6	77.4	7.7	6.9	0.0	0
O. tralucida	9	8	0	25.5	91.3	7.7	7.1	1.0	12
Ammonium sulfate, $(NH_4)_2SO_4$, 68.0 grams									
Control	9	0	0	24.4	97.3	6.9	7.4	0.0	0
O. tralucida	9	7	1	27.2	87.8	7.6	6.1	0.8	21
Ammonium diphosphate, $(NH_4)_2HPO_4$, 67.9 grams									
Control	9	0	0	30.4	92.2	7.8	8.3	0.0	0
O. tralucida	9	8	0	29.0	102.2	8.0	8.0	0.9	10
Calcium oxide, CaO, 28.7 grams									
Control	9	0	0	22.3	78.0	6.3	5.7	0.0	0
O. tralucida	9	9	4	28.1	66.8	7.2	7.2	1.6	55

TABLE 14 (*Continued*)

Treatment (formula), inoculum, and amount per square foot*	Plants inoculated			Average per living plant					Aborted roots†
	Total	Diseased	Dead	Diameter basal node	Length longest leaf	Green leaves	Primary roots		
							Healthy	Aborted	
	number	*number*	*number*	*mm*	*cm*	*number*	*number*	*number*	*percent*
Calcium nitrate, $Ca(NO_3)_2 \cdot 4H_2O$, 121.3 grams									
Control	9	0	0	27.2	77.8	7.8	7.4	0.0	0
O. tralucida	9	9	1	23.9	103.0	6.7	6.3	1.3	26
Calcium sulfate, $CaSO_4 \cdot 2H_2O$, 88.2 grams§									
Control	9	0	0	22.7	67.2	7.3	5.4	0.0	0
O. tralucida	9	9	0	26.8	70.4	7.6	7.5	1.4	16
Calcium diphosphate, $CaHPO_4 \cdot 2H_2O$, 88.2 grams§									
Control	9	0	0	25.4	63.2	7.7	7.1	0.0	0
O. tralucida	9	9	5	28.1	78.8	8.5	10.3	0.0	55
Calcium monophosphate, $CaH_4(PO_4)_2 \cdot 2H_2O$, 129.2 grams§									
Control	9	0	0	24.0	57.8	7.4	5.9	0.0	0
O. tralucida	9	9	3	28.4	55.2	8.2	8.2	1.8	46

* Chemicals dissolved in water and applied in 3 equal amounts at 7-day intervals beginning 2 days after inoculation.

† Percentage weighted to include dead plants which are assumed to have the same average number of roots as the living plants.

‡ Due to chemical injury.

§ Not soluble. Applied in mixture of white sand.

containers ranged at first from 2.6 to 9.0 or more, these values at the end of the experiment ranged only from 7.0 to 8.5. There was no evidence that the pH value of the top soil within this range exerted any direct influence on the amount of infection from omphalia.

Chemical injury to the plants resulted principally from the treatment with ammonium hydroxide. Four plants were killed by this treatment, though the relative growth of the remaining noninoculated plants was slightly greater than that of the untreated control plants.

Noninoculated plants showed no evidence of omphalia root rot at the end of the experiment (table 14). Infection by *Omphalia tralucida* was found in at least some plants from all inoculations except those which had been treated with ammonium hydroxide. The relative severity of the disease varied widely as shown by the number of dead plants and the aborted roots.

The effect of the chemical soil treatments on plant growth is indicated in table 14 by the diameter of the basal node, the length of the longest leaf, the number of green leaves, and the number of roots. These data indicate the average size of living plants at the end of the experiment. In some of the treatments, such as that with calcium diphosphate, the inoculated plants were larger than the noninoculated plants. This anomalous situation was attributed to the reduced competition between plants in the inoculated group which existed after several of the original number had been killed.

Growth of the different lots of chemically treated but noninoculated plants was compared with that of noninoculated control plants treated only with water (fig. 38, *A*). Calculations were made on the basis of 100, an arbitrary

number which represented the average growth of the control plants. The deviation from 100 was obtained for plants in each treatment by calculating the algebraic sum of the differences (in per cent) between plants of that treatment and the control plants in regard to diameter of basal node, length of longest leaf, number of green leaves, and number of primary roots, respectively. These arbitrary numbers were taken to represent the relative growth of the various lots.

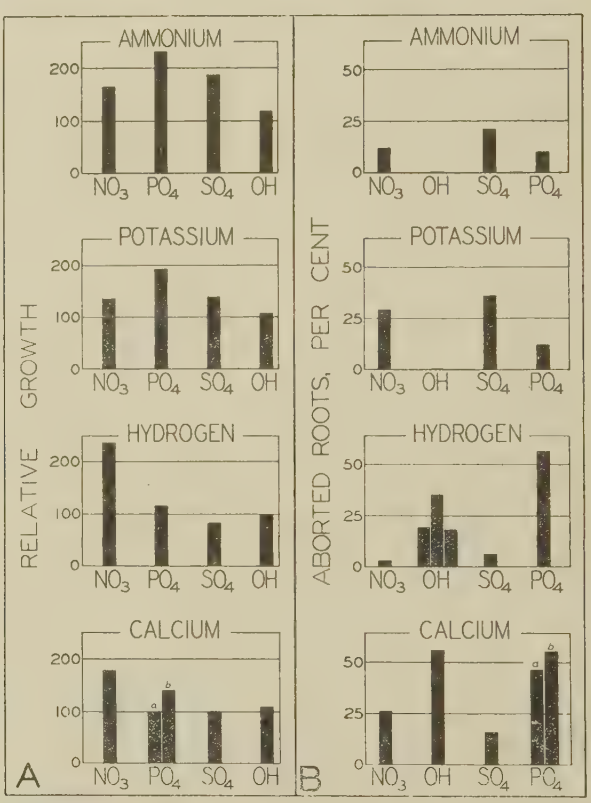


Fig. 38.—Histograms showing the effect of soil treatment with the nitrates, phosphates, sulfates, and hydroxides of ammonium, potassium, hydrogen, and calcium: *A*, on the relative growth of noninoculated date seedlings; and *B*, on the percentage of aborted roots on seedlings inoculated with *Omphalia tralucida*. Both calcium monophosphate, *a*, and calcium diphosphate, *b*, were tested.

On this basis, the treatments with nitric acid and ammonium diphosphate gave the greatest relative growth, whereas that with sulfuric acid caused stunting. As a group, the ammonium compounds produced the greatest relative growth and the calcium compounds the least. Similarly, the nitrates were most beneficial to growth and the hydroxides were the least beneficial.

The percentages of aborted roots in the different lots of inoculated plants seemed to hold an inverse relation to relative growth (fig. 38, *B*). Treatments with the ammonium compounds, considered as a group, resulted in the lowest

percentages of aborted roots, and those with the calcium compounds in the highest percentages. Although treatments with ammonium and potassium hydroxides had prevented root abortion, the nitrates as a group gave the most effective control of the disease; the phosphates were least effective. Some treatments, especially those with orthophosphoric acid, calcium hydroxide, and calcium diphosphate, seemed to increase the severity of attack.

Several plant diseases caused by soil-inhabiting fungi have been controlled to some extent by the use of soil amendments. Streets (*18*, *19*) reported experiments in which the phymatotrichum root rot of deciduous fruit and nut trees was controlled with anhydrous ammonia, ammonium sulfate, or ammonium phosphate. These results were attributed both to the stimulation of the susceptes and to the toxicity of these compounds to the pathogen. Leach and Davey (*38*) found that various nitrogenous fertilizers (ammonium sulfate, anhydrous ammonia, calcium nitrate, and cyanamide) were equally effective in reducing the percentage of *Sclerotium rolfsii* Sacc. infection on sugar beets when equivalent amounts of nitrogen were supplied under favorable conditions. Heavy applications of anhydrous ammonia and cyanamide to naturally infested soils failed to destroy the sclerotia or to reduce their viability.

Since chemical treatments in the experiments with omphalia root rot had been applied at 7-day intervals beginning only 2 days after inoculation, it seemed probable that the disease had not become well established at the time of treatment and that the observed beneficial effects might have resulted more from prevention than from treatment of the disease. Another experiment was conducted, therefore, to observe the development of disease when soil treatments were applied at different intervals after the time of inoculation. The purpose was to determine whether or not ammonium sulfate is capable of checking the development of the disease after the pathogen has become firmly established within the tissues of the suscept.

A uniform lot of Deglet Noor date seedlings was grown in fine sandy loam in 40 5-gallon containers. After 6 months there were from 7 to 9 vigorous, healthy plants in each container. The 40 containers were then separated into four equal groups for inoculation and treatment, but other environmental factors remained uniform. Five containers in each group were infested with 80 ml of *Omphalia tralucida* on bran; the others received only sterile bran. Ammonium sulfate, at the rate of 68 grams per square foot was distributed over the soil surface and then dissolved by means of irrigation water. Whereas the containers in group I received no chemical treatment (control), those in group II were treated 2 days after the time of inoculation, those in group III were treated 91 days after inoculation, and those in group IV, 183 days after inoculation.

The experimental plants were taken up one year after inoculation. Competition among plants had had considerable influence upon their size and vigor. In containers where a large proportion of the seedlings had been killed, the remaining plants had grown larger than the plants in containers where none had died. Some of the plants had developed stunted, pinnate leaves, but this condition could not be related to any experimental variable.

The untreated plants in group I (table 15) showed essentially the same results as had been obtained repeatedly in tests of this kind. No evidence of

omphalia root rot was found in plants from noninfested soil, whereas, in the infested soil, 40 per cent of the plants had died and 88 per cent of the others were diseased. The noninoculated plants had become chlorotic owing to lack of nitrogen. In group II the application of ammonium sulfate 2 days after inoculation had caused considerable chemical injury to the plants, but it had reduced markedly the percentage of infected plants and the relative development of the disease.

Severe chemical injury was again observed in plants of group III after

TABLE 15

GROWTH OF DEGLET NOOR DATE SEEDLINGS AND THE DEVELOPMENT OF OMPHALIA ROOT ROT AS AFFECTED BY THE INTERVAL BETWEEN INOCULATION AND SOIL TREATMENT WITH AMMONIUM SULFATE*

Inoculum, group no., and interval between inoculation and treatment	Total plants	Dead plants	Measurements of living plants (average)					Omphalia root rot	
			Diameter basal node	Length of longest leaf	Green leaves	Primary roots		Living plants with lesions	Relative development
						Healthy	Aborted		
	number	*number*	*mm*	*cm*	*number*	*number*	*number*	*percent*	
Plants inoculated with sterile bran:									
Group I, control	43	0	26	65	8.0	6.6	0.0	0	none
Group II, 2 days	43	9	26	70	8.6	6.7	0.0	0	none
Group III, 91 days	43	15	29	78	8.0	7.2	0.0	0	none
Group IV, 183 days	43	4	29	86	8.5	8.0	0.0	0	none
Plants inoculated with *Omphalia tralucida:*									
Group I, control	42	17	29	70	8.3	7.2	0.7	88	moderate
Group II, 2 days	42	4	26	72	7.7	7.0	0.8	29	slight
Group III, 91 days	42	19	31	92	8.8	8.1	1.2	100	moderate
Group IV, 183 days	42	16	33	94	9.7	7.7	2.1	100	moderately severe

* Applied to the soil surface at the rate of 68 grams per square foot.

treatment 3 months after inoculation. By that time the disease had already killed a number of the inoculated plants, and the pathogen had become well established in many others. A similar condition prevailed in group IV, though chemical injury was less severe. By comparing the condition of plants in groups III and IV with that of plants in group I, evidence indicated that the chemical treatments applied 3 to 6 months after inoculation had not checked the development of the disease. From the results in group II, it appeared that the chemical treatment prevents or reduces the amount of disease in situations where the pathogen has not become established within the suscept. Such a treatment should be considered, therefore, only because of its prophylactic value. Chemical injury to the plants would probably have been less marked if smaller amounts had been applied at weekly intervals. One heavy application had been made, however, on the supposition that a highly concentrated solution would be more apt to check the disease than one of low concentration.

Under field conditions, the early chemical soil treatments against omphalia root rot gave little or no evidence of control. Since the application of large quantities of various fertilizing materials had failed to improve the condition

of affected palms, it was thought that the palms, owing to many rotted roots, had been unable to absorb these nutrients. Although palms in some of the affected areas were destroyed, those in other areas, such as garden *Q*, were retained with the hope of later recovery. For several years the disease in this garden continued to spread. The heavy applications of animal and commercial fertilizers made in 1928 and 1929 were discontinued because of unfavorable economic conditions, and the orchard deteriorated into a very unproductive state. In July, 1937, a change in ownership resulted in an attempt to improve the condition by cultural means. The amount of irrigation water was doubled; and in 1937, 5 pounds of ammonium sulfate, 5 pounds of Cal-Nitro (a mixture of ammonium nitrate and dolomite containing 20.5 per cent nitrogen), and 240 pounds of dairy manure were applied per tree. A heavy winter covercrop of Hubam clover was grown. In 1938, 20 pounds of soil sulfur and 12 pounds of Cal-Nitro were applied in addition to 400 pounds of steer manure. In 1939, after turning under another crop of Hubam clover, each palm received 20 pounds of soil sulfur, 6 pounds of calcium nitrate, and later, 6 pounds of Cal-Nitro. As a result of continuing this fertilizer practice and, in 1939, applying in the irrigation water certain minor elements (iron 0.5 p.p.m., manganese 0.5 p.p.m., zinc 0.05 p.p.m., copper 0.02 p.p.m., and boron 0.1 p.p.m.), the palms in garden *Q* became noticeably greener and more vigorous than in July, 1937.

Surveys made at yearly intervals indicated that at some time between 1928 and 1940, 144 palms in the oldest block of garden *Q* had shown symptoms of decline. By comparing their condition in the period 1938 to 1940 with that from 1928 to 1937, the condition of 5 palms was found to be worse, that of 63 palms was the same, and that of 76 palms was improved. This encouraging result indicated that the new cultural operations had checked the spread of the disease and that improvement had been made in the condition of many palms which at some time had shown mild secondary symptoms. Among the 68 palms whose condition was either unchanged or worse were the severely affected palms which for years had been stunted and worthless. Although the benefits of good cultural management were clearly evident, the question still remained whether or not such management could make very sick palms commercially productive. Other evidence that high soil fertility alone could not control or prevent this disease lay in the fact that in garden *Q* during 1928 and 1929, omphalia root rot was spreading rapidly. Furthermore, many disease-resistant seedling palms in this planting continued to grow rather vigorously throughout the entire period of observation, while the susceptible Deglet Noor palms became stunted (fig. 37). From the evidence now at hand, it seems probable that when palms become severely affected with omphalia root rot, they should be destroyed. They are a menace to other palms and an economic liability to the grower.

ERADICATION

During recent years considerable progress has been made in the eradication of various soil fungi by soil disinfection. Fawcett (*20*) reports that in southern California citrus orchards carbon disulfide was used successfully against *Armillaria mellea* as early as 1918. Thomas and Lawyer (*51*) found that low soil moisture was the most important single factor in the treatment with carbon disulfide and that armillaria could be killed in soil to a depth of 60 inches

when 45 ml of this disinfectant was applied 8 to 9 inches deep at 18-inch staggered intervals.

According to King, Loomis, and Hope (*35*), individual sclerotia of the cotton-root fungus, *Phymatotrichum omnivorum,* were killed by immersion for 30 minutes in a 1 per cent solution of Formalin (40 per cent solution of formaldehyde). King and Hope (*33*) attempted to eradicate this fungus from an area near Indio, California, by injecting under pressure a 1¼ per cent solution of Formalin into the soil through pipes to a depth of 6 feet and at the rate of 1 gallon per cubic foot. Ezekiel and Taubenhaus (*18*) compared several chemicals, including certain chlorinated hydrocarbons and other volatile materials, for their relative toxicity to the cotton-root fungus and their ability to penetrate soil. When these materials were tested in the laboratory, pentachloroethane and tetrachloroethane were the most promising. In the field (*19*), both these chemicals and industrial xylol killed the fungus in roots to a depth of 4 feet when applied at the rate of 500 p.p.m. of soil weight. Only scattered and stunted cotton plants were obtained, however, from plantings made 3 months after the treatment with tetrachloroethane.

Oserkowsky (*45*) tested the fungicidal effect on *Sclerotium rolfsii* of a number of compounds in aqueous solution and in the gaseous state. Sclerotia were killed after 3 days' exposure at 25° to 26° C to the saturated vapors of 18 compounds including carbon disulfide. The vapor of chloropicrin was reported to be nonlethal. Davey and Leach (*16*), however, found chloropicrin, though difficult to confine, rather effective in killing the sclerotia in piles of screenings at sugar-beet receiving stations. When properly confined, 2 ml of chloropicrin per square foot of soil surface, injected to a depth of 6 inches, killed the sclerotia to a depth of 1 foot.

Godfrey (*24*) found chloropicrin to be an effective fumigant against 7 species of soil fungi, including *Sclerotium rolfsii* and *Armillaria mellea,* and also (*23*) against the root-knot nematode, *Heterodera marioni* (Cornu). The importance of confining the gases used for soil fumigation was also stressed (*22, 25*).

Soil-disinfection experiments against *Omphalia* spp. were initiated in October, 1933, when an area of 3 diseased palms in garden *A* was treated with carbon disulfide. The treatment was similar to that suggested by Fawcett (*20*) for the eradication of *Armillaria mellea.*

Soil-disinfection studies were also made at Riverside to compare the efficiency of various fungicides and to determine the effect of such treatments on the soil for subsequent planting. Two series of experiments were conducted in galvanized iron containers, 13.5 inches in diameter and 23 inches deep, with segments of Deglet Noor date roots that had been artificially inoculated with *Omphalia tralucida* and buried in fine sandy loam. The root segments were placed in a horizontal position and at different depths ranging from 1 to 21 inches. This was done at the time the containers were filled with air-dry soil and tamped. Large holes for drainage in the bottom of the containers had been covered with pieces of tile but not plugged. After treatment, the surface of the soil was covered with 2 thicknesses of waxed paper and ½-inch layer of soil. Under these conditions the soil was covered, but it was not sealed against the escape of the fumigating gases.

In the first series of experiments (7), carbon disulfide, Formalin, tetrachloroethane, and chloropicrin were used. A basic treatment that had been used effectively against some other soil fungus was chosen for each fungicide. On the basis of 1 square foot of surface area, the basic dosage for carbon disul-

TABLE 16

VIABILITY OF *Omphalia tralucida* IN DATE ROOTS AT SEVERAL DEPTHS 1 MONTH AFTER SOIL DISINFECTION WITH FOUR FUNGICIDES

Fungicide, dosage per square foot of surface area, and container no.	Viability 1 month after treatment				
	At 1-inch depth	At 6-inch depth	At 11-inch depth	At 16-inch depth	At 21-inch depth
None (control)					
Container no. 1	++*	++	++	++	++
Container no. 2	++	++	++	++	++
Container no. 3	++	++	++	++	++
Container no. 17	++	++	++	++	++
Carbon disulfide					
14.2 ml					
Container no. 4	−−	−−	−−	−−	−−
Container no. 5	−−	−−	−−	−−	−−
28.4 ml					
Container no. 6	−−	−−	−−	−−	−−
Container no. 18	−−	−−	−−	−−	−−
Formalin†					
70.4 ml‡					
Container no. 7	++	++	+−	−−	++
Container no. 8	+−	++	++	++	++
140.8 ml‡					
Container no. 9	−−	−−	++	−−	++
Container no. 10	−−	−−	−−	++	+−
Tetrachloroethane					
6.7 ml					
Container no. 11	++	++	++	++	++
Container no. 12	++	++	++	++	++
13.3 ml					
Container no. 13	−−	−−	−−	++	++
Container no. 19	−−	−−	++	++	++
Chloropicrin					
4.7 ml					
Container no. 14	−−	−−	−−	−−	−−
Container no. 15	−−	−−	−−	−−	−−
9.3 ml					
Container no. 16	−−	−−	−−	−−	−−
Container no. 20	−−	−−	−−	−−	−−

* + = fungus viable, and − = fungus nonviable; each + or − represents a separate test.
† 40 per cent formaldehyde by volume.
‡ Applied as a drench in 6.9 liters of water.

fide was 14.2 ml (0.5 liquid ounce); for Formalin, 70.4 ml in 6.9 liters of water (1 per cent); for tetrachloroethane, 6.7 ml (100 p.p.m. dry weight of soil); and for chloropicrin, 4.7 ml. A second treatment for each fungicide was obtained by doubling the basic dose. The chemicals were poured into holes that were made by driving a metal rod to a depth of 18 inches at the center of each container. These holes were closed immediately and the soil was covered, as previously explained.

The root segments were taken up 1 month after treatment. Viability of the

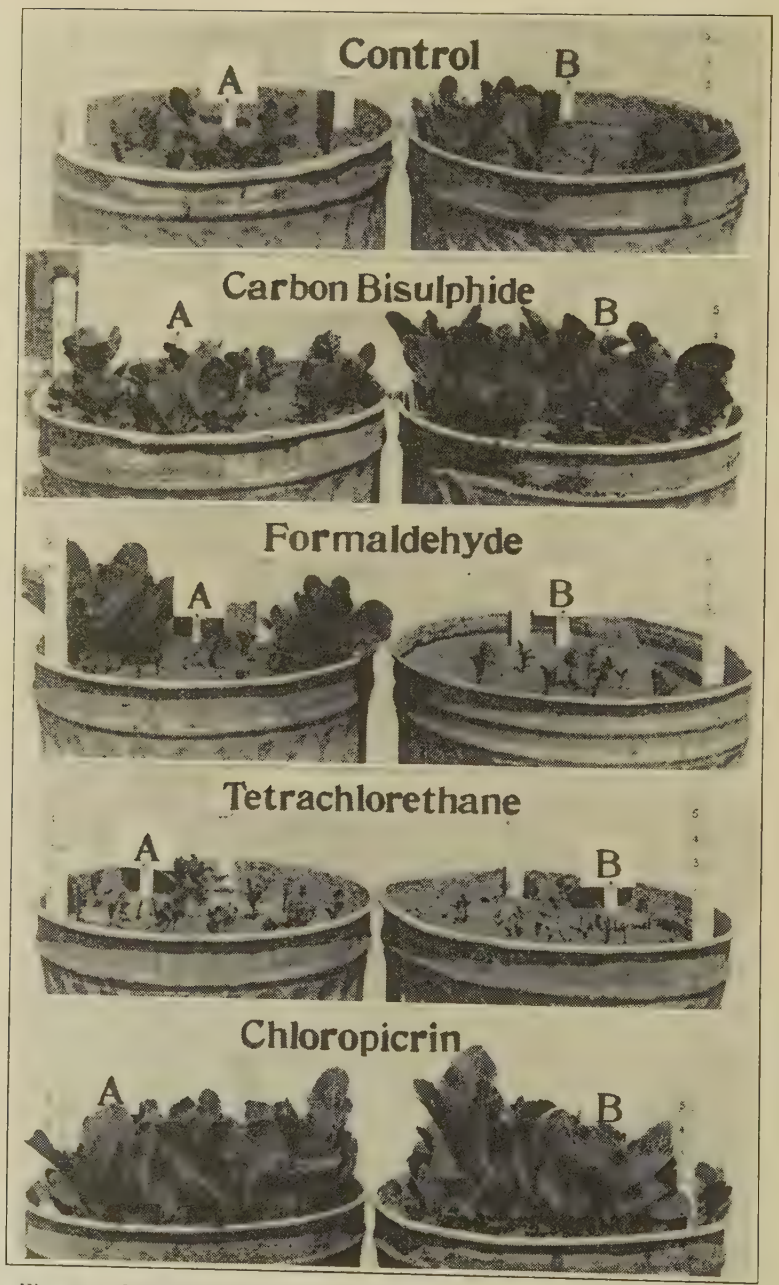


Fig. 39.—Cauliflower seedlings growing in untreated soil (control) and in soil that had been disinfected with carbon disulfide, formaldehyde, tetrachloroethane, and chloropicrin: *A*, basic dose (see p. 99); *B*, twice basic dose. Graduations in inches.

fungus was tested in the laboratory by means of tissue plantings on corn-meal agar (table 16). Two tissue plantings were made from each root segment. The living mycelium of *Omphalia tralucida* developed in all cases from roots in untreated soil, but in none from roots in soil that had been fumigated with carbon disulfide or with chloropicrin. The basic dosages of Formalin and

TABLE 17

VIABILITY OF *Omphalia tralucida* IN DATE ROOTS AT SEVERAL DEPTHS AS AFFECTED BY SOIL DISINFECTION WITH SEVEN FUNGICIDES

Fungicide* and dosage per square foot of surface area	Viability 18 days after treatment					Viability 40 days after treatment				
	At 1-inch depth	At 6-inch depth	At 11-inch depth	At 16-inch depth	At 21-inch depth	At 1-inch depth	At 6-inch depth	At 11-inch depth	At 16-inch depth	At 21-inch depth
None (control)	+†	+	+	+	+	+	+	+	+	+
	+	+	+	+	+	+	+	+	+	+
Carbon disulfide										
3.7 ml	+	−†	+	+	+	−	−	−	−	−
7.4 ml	+	+	+	+	+	−	−	−	−	−
14.8 ml	+	+	+	+	+	−	−	−	−	−
Chloropicrin										
1.3 ml	−	−	−	−	+	−	−	−	−	−
2.5 ml	−	−	−	−	−	−	−	−	−	−
5.0 ml	−	−	−	−	−	..	..	..	..	..
7.5 ml	..	..	..	..	..	−	−	−	−	−
Chlorine										
81.0 grams	+	+	+	−	+	+	+	+	−	−
162.0 grams	+	+	−	−	+	+	+	−	−	−
323.0 grams	−	−	−	−	−	−	−	−	−	−
Sulfur dioxide										
73.0 grams	+	+	−	−	+	+	+	+	−	+
292.0 grams	+	+	−	−	−	+	+	−	−	−
Ammonium hydroxide										
27.6 ml‡	..	..	..	..	..	+	+	+	−	+
110.4 ml‡	+	+	−	+	+	..	..	..	..	..
Ethylene oxide										
5.0 grams	..	..	..	..	..	−	−	−	−	−
45.0 grams	−	−	−	−	−	..	..	..	..	..
Dichloroethyl ether										
14.8 ml	..	..	..	..	..	−	+	+	+	+
29.6 ml	+	+	+	+	+	..	..	..	..	..

* All chemicals except ammonium hydroxide were applied at a depth of 18 inches and in the center of the container.

† + = fungus viable, and − = fungus nonviable.

‡ C.P. 0.90 specific gravity, 28.5 per cent NH_3, applied in 28 liters of water.

tetrachloroethane had little or no lethal effect on the fungus, though the larger doses of these chemicals were partially effective.

On the same day that the root segments were taken up, 200 cauliflower seeds of the Henderson's Early Snowball variety were planted in each container to test the condition of the treated soil for subsequent planting. Although cold weather retarded the germination and growth of the seedlings, marked relative differences between lots had appeared within 2 months (fig. 39). A summary of emergence and average fresh weight of the seedlings indicated that disinfection with chloropicrin had improved the soil for subsequent planting. Treatments with carbon disulfide and with the basic dose of Formalin had also stimulated growth to a moderate degree. Tetrachloroethane and the

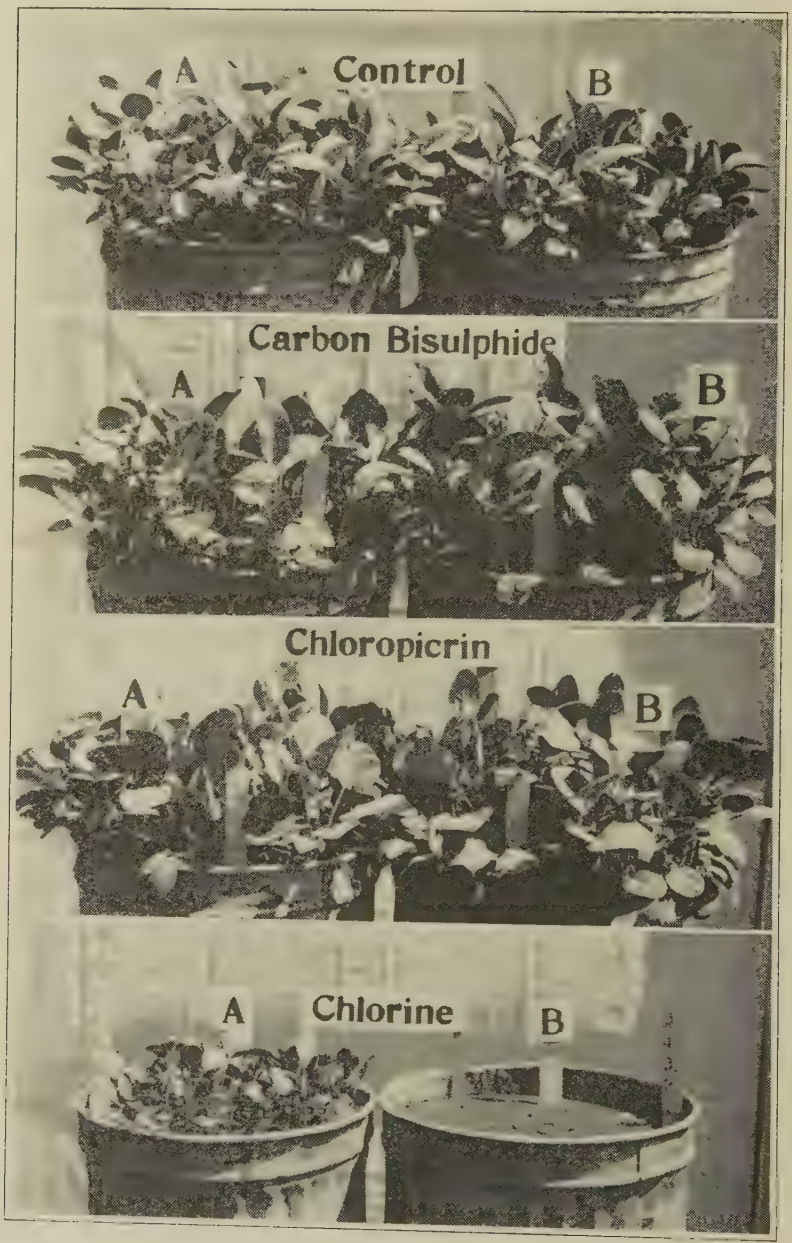


Fig. 40.—Cauliflower seedlings growing in untreated soil (control) and in soil treated (on the basis of 1 square foot surface area) with carbon disulfide: *A*, 3.7 ml; *B*, 14.8 ml; chloropicrin: *A*, 1.3 ml; *B*, 5.0 ml; and chlorine: *A*, 81 grams; *B*, 323 grams.

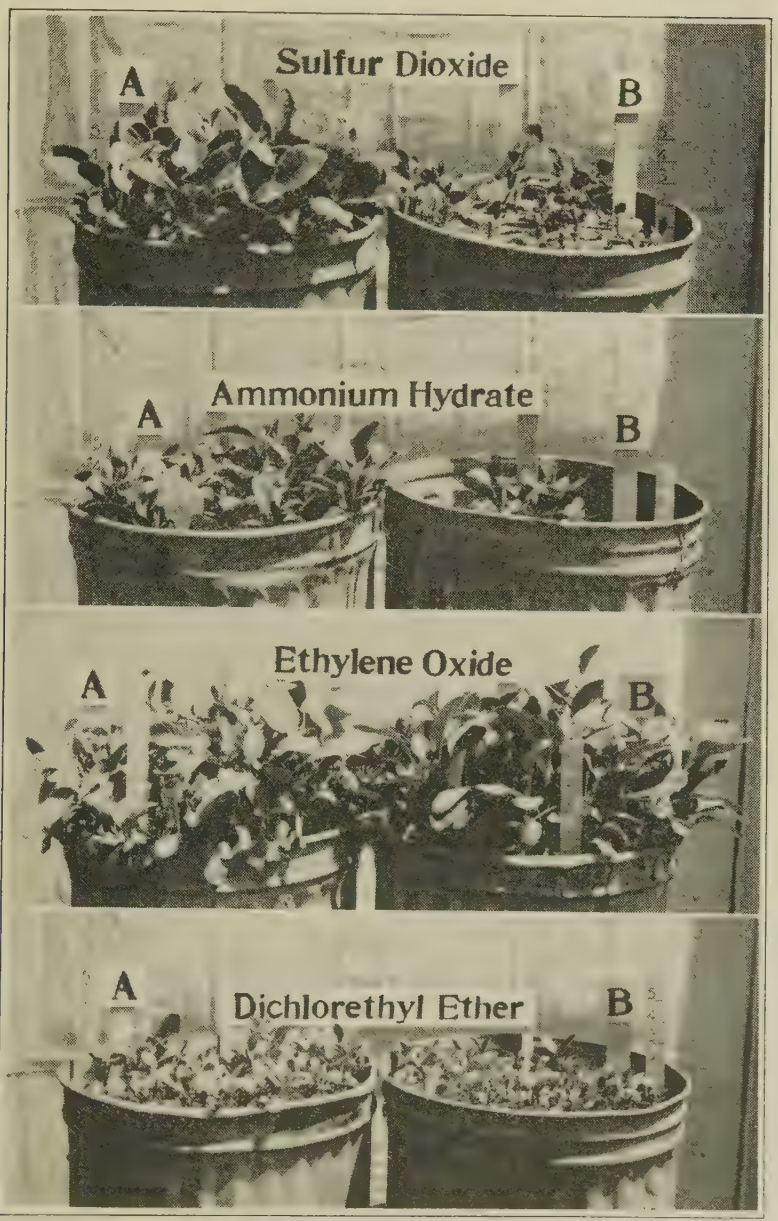


Fig. 41.—Cauliflower seedlings growing in soil treated (on the basis of 1 square foot surface area) with sulfur dioxide: *A*, 73 grams; *B*, 292 grams; ammonium hydroxide: *A*, 28 liters NH_3 250 p.p.m.; *B*, 28 liters NH_3 1,000 p.p.m.; ethylene oxide: *A*, 5 grams; *B*, 45 grams; and dichloroethyl ether: *A*, 14.8 ml; *B*, 29.6 ml.

higher dosage of Formalin, however, had remained in the soil in such high concentrations that the soil was not as yet favorable to plant growth.

In the second series of experiments two to four dosages of carbon disulfide, chloropicrin, chlorine, sulfur dioxide, ammonium hydroxide, ethylene oxide, and dichloroethyl ether were applied (table 17). All chemicals except ammonium hydroxide were applied at a depth of 18 inches and in the center of the container. The liquids were poured down a long-necked funnel and the gases were delivered through a perforated metal tube. The given amounts of C.P. ammonium hydroxide were each diluted in 28 liters of water and applied as a drench which was calculated to saturate the entire mass of soil.

Viability tests were made on the fungus in half the containers 18 days after treatment and in the other half, 40 days after treatment (table 17). Viable mycelium of *Omphalia tralucida* was recovered from each of the untreated roots. The lethal action of carbon disulfide was not evident after 18 days, but it was very evident after 40 days. Under the conditions of this experiment all the fungus in 2 cubic feet of soil was killed by the application of 3.7 ml of carbon disulfide. But with chloropicrin, dosages as low as 2.5 ml for 18 days and 1.3 ml for 40 days were lethal at all depths. Soil treatment with ethylene oxide was also very effective. Less effective or rather unsatisfactory were the other treatments with chlorine, sulfur dioxide, ammonium hydroxide, and dichloroethyl ether.

The soil in each container was planted as before with 200 seeds of cauliflower, 46 days after treatment. Favored by climatic conditions, the percentage of emergence was relatively high and growth was rapid in certain containers. Differences in the appearance of the various lots were very marked after 50 days (figs. 40, 41). When the plants were taken up, competition, apparently, had already been a factor in limiting the growth where the stand of plants was relatively dense.

The average fresh weight of the plants, including leaves and stems above the soil line, was taken as a measure of growth in relation to previous soil treatment. The treatment with chloropicrin had again been outstanding in stimulating growth besides increasing the percentage of emergence. Carbon disulfide seemed to stimulate growth but the number of plants was reduced. Whereas ethylene oxide had increased emergence, the plants were so crowded that the average fresh weight was only a little greater than that in the control. Emergence was much reduced where chlorine had been used. Also, inferior results were obtained in soils treated with sulfur dioxide, ammonium hydroxide, and dichloroethyl ether.

Chloropicrin, carbon disulfide, and ethylene oxide, having given the most encouraging results in the preliminary experiments, were then considered on the basis of relative adaptability to field conditions. Ethylene oxide, a gas under ordinary conditions of temperature and pressure, was ruled out because no practical method of application was known. (Doses for the preliminary experiments had been weighed by difference on a solution balance.) The other two chemicals, being liquids, could therefore be measured by volume in the field.[15] In 1935 the comparative costs of these chemicals were studied by obtain-

[15] During the course of this investigation, hand applicators with automatic measuring devices were developed and placed on the market by commercial companies.

ing bids on the open market from six leading chemical companies (*7*). Based on the amounts of these materials that were required for soil disinfection, the cost of chloropicrin at that time was considerably higher than that of carbon disulfide. Since then, this difference in cost has decreased.

In soil-disinfection experiments against *Armillaria mellea* highly practical findings were demonstrated. Whereas in open sandy soils the lethal effect of chloropicrin was limited to a vertical distance of 12 to 24 inches from the site of application, that for carbon disulfide extended to a depth of at least 60



Fig. 42.—Soil disinfection with carbon disulfide in an omphalia-root-rot area. The operator at the left is pushing an iron rod into the soil to make a hole for the disinfectant. The other operator is applying liquid carbon disulfide by means of a homemade applicator. Much better applicators are now available.

inches. Since date roots containing viable mycelium of omphalia had been found to a depth of 48 inches, it was thought that eradication of the fungus could be achieved more easily with carbon disulfide than with chloropicrin. For these reasons, carbon disulfide has been used exclusively in the field where efforts have been made to eradicate this fungus.

During 1933 to 1935, inclusive, about 50 tree squares in 6 gardens were disinfected. The usual procedure was as follows: The diseased palm was removed and destroyed. When the soil had become dry, a rectangular area, 30 feet square and extending half way to the surrounding palms, was cross-marked into smaller squares measuring 2 feet on a side. Holes, 18 inches deep, were made with a sharpened steel rod at the corners of the small squares (fig. 42). Carbon disulfide was then injected into these holes by means of an

applicator capable of delivering approximately 2 liquid ounces (59 ml) per dose. The holes were closed immediately and the soil was covered with layers of burlap or paper, and, when possible, sprinkled with water to prevent rapid escape of the fumes. The dosage was increased to 6 liquid ounces per hole in the spot where the diseased palm had stood. The soil cover was left in place for 3 weeks or until the odor of carbon disulfide had disappeared. After that time the soil was considered safe for replanting.

In the first soil-disinfection treatment in garden *A*, 10 gallons of carbon



Fig. 43.—A vigorous young Deglet Noor date palm that had been replanted as an offshoot in an omphalia-root-rot area after soil disinfection with carbon disulfide. The palm was five and a half years old when photographed.

disulfide was applied in an area about 3 diseased trees. Only one of the trees had been removed before treatment, but for all 3 the dosage of carbon disulfide was doubled in or immediately surrounding the location of the trunk. One of the remaining palms was dissected 10 weeks after the treatment. All roots below the soil line were dead, though a few young primary roots behind leaf bases and standing above the soil line were still alive. Omphalia was not recovered from this palm, though 40 tissue plantings were taken. The fungi most commonly obtained were *Trichoderma lignorum, Ceratostomella radicicola, Phomopsis phoenicicola, Cephalosporium* sp., *Fusarium* spp., and *Mucor* sp. About 6 months after the treatment, this area was replanted with 3 healthy Deglet Noor offshoots, which developed rapidly and without symptoms of omphalia root rot (fig. 43). No further spread of the disease has been detected from this area.

A larger area in garden *C* was treated in May, 1934. After the removal of 21 diseased trees, the land was marked off so that 6 tree squares were left as untreated control areas, and the remainder was disinfected. Because of the loose, sandy nature of the soil, the holes for the carbon disulfide were hard to

make, but this was overcome by moistening the surface first. Healthy-rooted offshoots of the Deglet Noor and Khadrawy varieties were replanted in equal numbers in the experimental area after the treatment. In 1941, root specimens were taken from 7 of the weaker palms. *Omphalia tralucida* was isolated only from a Deglet Noor palm which stood in untreated soil in a place where another severely affected palm had stood. The secondary symptoms of the disease were already evident. Two other Deglet Noor palms and 3 of Khadrawy in untreated soil appeared to be free from infection, as were also the 15 palms in the treated soil.

TABLE 18

VIABILITY OF *Omphalia tralucida* IN DATE ROOTS AT SEVERAL DEPTHS AFTER SOIL DISINFECTION WITH CARBON DISULFIDE*

Garden and series	Viability after treatment				
	At 6-inch depth	At 18-inch depth	At 30-inch depth	At 42-inch depth	At 54-inch depth
Garden *J*					
Series 1	−†	−	−	.	−
	+	−	−	..	−
Series 2	+	−	−	−	−
	−	−	−	−	−
Garden *B*					
Series 3	−	−	−	−	
	−	−	−	−	
Series 4	..	−	−	−	−
	.	−	−	−	−
Control					
Series 5	..	++++++++	..	..	..
		+−−−−−−−			

* Applied 2 liquid ounces at intervals of 2 feet and 18 inches deep.
† + = fungus viable, and − = fungus nonviable; each + or − represents a separate test.

In 1934, 20 Deglet Noor palms were destroyed in garden *V* because of the omphalia root rot. The soil in 13 of these tree spaces was disinfected with carbon disulfide. After the treatment, 20 healthy offshoots of the same variety were planted in the empty spaces, though 7 of these spaces had not been disinfected. *Omphalia tralucida* was isolated five years later from the roots of 2 of the palms in untreated soil. No evidence of the fungus was found in 2 other palms in untreated soil or in 3 palms from treated soil.

In 1935, while disinfecting two small areas in gardens *J* and *B*, artificially inoculated segments of date roots were buried in the soil at different depths to test the efficiency and penetration of the carbon disulfide. Vertical holes were made with a soil tube to a depth of 54 inches. The segments were then lowered into these holes by means of strings to depths of 6, 18, 30, 42, and 54 inches, respectively, while the holes were being filled with dry soil. The soil in garden *J* was a fine sandy loam except for a clay-bearing stratum about 12 inches below the surface. The carbon disulfide, applied at a depth of 18 inches, apparently did not penetrate upward through this clay-bearing stratum sufficiently to eradicate the fungus near the surface (table 18). Similar treatment in garden *B*, where the soil was porous and free from impervious layers, was effective in eradicating the fungus at all depths. Other inoculated roots were

buried without soil disinfection in fine sandy loam in a metal container. Omphalia was recovered from 9 out of 16 root segments. Thirteen naturally infected roots in the upper 4 feet of soil in garden *B* contained no viable mycelium of omphalia after the treatment.

Trichoderma lignorum was commonly obtained from date roots that had been subjected to soil disinfection with carbon disulfide. This is of interest because Weindling (*52*) found that in culture, omphalia was subject to attack by this fungus in much the same way that *Rhizoctonia solani* Kühn was attacked. The writer found that trichoderma exerted little or no inhibiting influence on omphalia in the soil, however, because infection occurred regardless of its presence. Possibly trichoderma may in some way help to kill the omphalia in the roots after soil disinfection.

In recent treatments against omphalia in gardens *O* and *I*, the method of applying carbon disulfide has been modified: 2 liquid ounces of the disinfectant was placed every 18 inches in holes 6 to 8 inches deep. The applications were staggered in alternate rows so as to make a triangular or diamond-shaped pattern. In light soils, the surface layer was moistened with water to a depth of 3 or 4 inches just before treatment and then kept moist by repeated sprinkling or covered with paper or burlap to hold the gas in the soil. In heavy soils, the surface layer was moistened immediately after treatment. The use of hand applicators, which are now available, reduced the cost of labor.

GENERAL DISCUSSION

In considering the problem of omphalia root rot, one should think not only of the present situation but also of the influence it may exert on the date industry of the future. If it had been recognized at first as a pathogenic root rot and a potential threat to the date industry, complete eradication might have been possible. Even now there is the question "Shall we attempt to eradicate omphalia or shall we learn to tolerate it?" So far as is known, the soils in the Coachella Valley were free from infestation before the introduction of the date palm. The pathogen in the localized infestations that now occur could probably be eradicated, but it is doubtful that public sentiment is sufficiently aroused to warrant such a difficult project.

If complete eradication is not practicable, it is highly desirable to control and to limit the spread of omphalia root rot wherever possible. Such steps have been taken thus far only by certain well-informed growers who have been impressed by the serious nature of the disease.

For the positive diagnosis of omphalia root rot, one should rely entirely upon the presence of the pathogen and the primary symptoms, because secondary symptoms may be confused with the effects of malnutrition and other troubles. The most satisfactory method of identification involves the isolation of fungi from roots, and the inoculation of young seedling date palms with cultures that resemble *Omphalia pigmentata* or *O. tralucida*. This process requires a period of 4 weeks or more. Although somewhat tedious, it does not require the production of fruiting bodies of the causal fungi and it distinguishes clearly between *Omphalia* spp. and other nonpathogenic Basidiomycetes.

Omphalia root rot does not usually cause death except in young seedlings.

The latent period between infection and the appearance of secondary symptoms varies from a few days to five or seven years, according to the size of the palm. Infected but healthy-appearing palms usually occur about the margin of a diseased area. Omphalia may be isolated more easily from palms in the early stages of decline than from those that have long been affected. Whether omphalia kills a root by invading it from one end to the other or merely by occupying a limited zone near the base of the trunk is not known. Omphalia may be only one in a succession of different fungi that destroy the roots. Local lesions produced by the primary invasion of omphalia may initiate a series of processes in the root which lead to general necrosis and disintegration. In fact, these lesions may exert some toxic effect upon the entire palm.

Partial recovery from omphalia root rot has been indicated by the favorable response of some palms to increased irrigation and fertilization. It seems fairly certain, however, that severely affected palms do not recover sufficiently from the effects of the disease to become commercially profitable. Nitrogenous compounds have been found to have some value in preventing infection, but there is no evidence that they will cure after the disease has become established.

Although capable of producing spores, *Omphalia pigmentata* and *O. tralucida* are propagated almost entirely by the sterile mycelium. No fruiting bodies of these fungi have been recognized in the Coachella Valley. The exact means by which they spread in the orchard from one palm to another has not been discovered, but such spread does occur. A likely method is by mycelial growth through the soil or along the roots. No sclerotia or other resting bodies are known. Some free mycelium may be in the soil, but no means have been devised for its detection. It has been isolated only from plant tissues in which it is capable of existing indefinitely as a saprophyte.

Transplanted offshoots from diseased palms are the most common source of new disease areas. At first, diseased offshoots were propagated without knowledge of the disease. Then the belief that the disease was caused by a nutritional disturbance led to the transplanting of affected offshoots without fear of transmitting the trouble. Not until the disease in such palms had completed the long latent period had it become certain that decline was transmissible. Because of present knowledge, suspicion is placed on all offshoots that originate within or near an infested area. Offshoots of the Deglet Noor variety have become so plentiful that there is no longer any justification in using diseased planting stock or that which has grown in proximity to diseased trees.

It is unfortunate that the Deglet Noor variety, which now represents 77 per cent of the total acreage of date palms in California, should be so susceptible to omphalia root rot. This fact should not be interpreted to mean that the variety is doomed. On the contrary, a large proportion of the plantings appear to be free from infection. These plantings can be kept free from omphalia if preventive measures are taken.

The use of healthy offshoots in noninfested soil appears to be the most important and the most practical control measure that has been found. There are at least three methods of treating infested soil: First, the land may be abandoned or used for some crop that is not affected; second, disease-resistant varieties of dates may be planted; and third, the infestation may be eradicated

by means of soil disinfection, after which healthy offshoots of any variety may be replanted. The abandonment of date land usually represents a severe financial loss because of the high initial cost of bringing dates into production. No other crops are known to be susceptible to attack. Grapefruit might be substituted for dates if the economic situation were favorable, but, at present, this seems doubtful. The substitution of disease-resistant dates appears more promising. Information on the relative susceptibility of date varieties is incomplete but there are indications that certain good horticultural varieties such as Khadrawy, Halawy, and Zahidi may be grown in omphalia-infested soil.

Eradication by means of soil disinfection is particularly suited to the smaller diseased areas where the cost of treatment is low in comparison to the ultimate loss that might result from continued spread. This treatment involves the destruction of the infected palms, the fumigation of the soil, and usually the replanting of healthy offshoots. Carbon disulfide is recommended for this treatment. It is effective and noninjurious to the soil. Also it is apparently less expensive than chloropicrin. The principal objection to carbon disulfide is its inflammability, but this danger can be easily avoided.

Regulatory measures against the spread of omphalia root rot have been considered but none have been adopted (*42*).[16] The situation will be handled for the present on an informal basis with the hope that the date growers will coöperate in controlling the disease.

SUMMARY

Although omphalia root rot has affected only about 1 per cent of the total acreage devoted to date culture in the Coachella Valley of California, it is important because of the threat it offers to the industry by its further spread.

The trouble, first recognized in 1921 near Indio, was found in four plantings of imported Deglet Noor palms by 1927 and is now known to be in 23 different properties, all in Riverside County. Whether the disease was introduced to California on date palms from the Old World or whether it is indigenous to the Coachella Valley is uncertain, although, from the evidence presented, the disease was apparently introduced.

Two types of symptoms are recognized: (1) primary symptoms that have to do with the direct pathogenic effect of the disease on parts actually invaded by the pathogens and (2) secondary symptoms that include the indirect effects of the disease on parts usually at some distance from the site of mycelial invasion. The typical primary symptom is a necrotic lesion which is usually confined to the underground portion of the palm and its developing offshoots. The abortion of young roots is the most damaging type of injury. Secondary symptoms include the premature wilting and death of the older leaves, the retardation of terminal growth, the reduction in size and number of fruit-stalks, and the development of small, worthless fruit. Death usually occurs only in young seedling palms.

A theory that this disease was caused by faulty nutrition was tested by

[16] A list of all known affected properties is available through the California State Department of Agriculture. Since October 1, 1943, palms or their offshoots have been refused admittance into all of that portion of San Diego County east of the range line between ranges 3 and 4 east, under authority of Section 124 of the Agricultural Code.

applying many different chemicals to the soil. Tolerance of the date palm to relatively high concentrations of these compounds and the inability of severely diseased palms to benefit from generous applications of plant nutrients were indicated.

A wide variety of microörganisms from the roots and trunks of diseased palms was tested. Two types of sterile white fungi, later described as *Omphalia pigmentata* Bliss and *O. tralucida* Bliss, predominated and were constantly associated with the disease. *O. pigmentata* was cultured from palms in 8 gardens; *O. tralucida,* from palms in 20 gardens. After inoculation, symptoms were produced on experimental plants similar to those observed on naturally infected palms in the field. Inoculations on young potted seedlings, three-year-old seedlings in the field, and on rooted offshoots of 18 varieties grown under orchard conditions in the Coachella Valley, repeatedly demonstrated the pathogenicity of these two fungi now considered to be the causal agents of the disease.

Sporulation of *Omphalia* spp. was induced on inoculated seedlings of *Washingtonia filifera* under artificial conditions of temperature (26° to 31° C) and relative humidity (92 to 98 per cent). Basidiospores from the small sporophores were cultured and found to be pathogenic. In culture *O. pigmentata* may be distinguished from *O. tralucida* by its characteristic pigment line (light orange yellow to cadmium [*46*]).

The date palm, *Phoenix dactylifera,* is the only naturally infected suscept, but the susceptibility of the native fan palm, *Washingtonia filifera,* and of the ornamental date palm, *Phoenix canariensis,* was demonstrated by artificial inoculations.

The pathogen enters the palm by direct mycelial penetration through the cuticle and outer epidermal wall. A mat of fungus hyphae first becomes closely attached to the surface. The starch grains are dissolved from the underlying cells which become discolored and die. The mycelium then invades the necrotic tissue and fills each cavity. The attack on the leaf bases is, in most cases, only a preliminary stage in the more important root-rot phase of the disease. The older leaf bases that cover the lower end and sides of the trunk constitute a physical barrier through which the roots must penetrate.

The length of time between infection and the appearance of secondary symptoms (latent period) may vary from a few days to five years or more according to the size and age of the suscept, the concentration of the inoculum, and the environment. A rather sudden decrease in vegetative vigor follows, and finally, an equilibrium may be reached between pathogen and suscept whereby the latter continues to live at a very subnormal level of health.

Rapid development of omphalia root rot occurred in soil at 24° to 38° C. The optimum soil temperature for the disease was 31°, or slightly above, whereas that for terminal growth of date roots was about 24°. The date palm and these root-rot fungi are best adapted to relatively high soil temperatures such as those found in the Coachella Valley during the summer months.

Potted seedling date palms remained alive for three years in soil continuously covered with water. Continuous immersion of date roots, starting 48 hours after inoculation, prevented infection by omphalia.

Moderate to severe infection occurred in soil in the pH range from 5.11 to

9.65. In 5 date gardens the pH values of soil ranged from 6.60 to 7.94 at field moisture content and from 7.84 to 9.83 at 1 : 5 ratio of soil to water.

Omphalia root rot may occur in soils that vary widely in salt concentration.

Omphalia root rot may spread outward in all directions from a focus of disease at the rate of 30 to 60 feet per year. Secondary symptoms have been observed only in the Deglet Noor variety, though *Omphalia* spp. have been isolated from the roots of Zahidi, Tafazwin, Saidy, Khadrawy, Horra, and Iteema palms.

Whereas the reactions of Deglet Noor palms to the pathogens may include severe stunting in addition to root necrosis, the reactions of palms of other varieties may include only a slight amount of necrosis in the roots.

Because of the lag between the appearance of primary and secondary symptoms, infected but healthy-appearing palms commonly occur at the margin of an enlarging diseased area. The survey method of diagnosis is therefore less accurate than the laboratory method. Three phases have been distinguished in the history of a diseased area, which has been known since 1921: (1) the latent period, 1915(?)–1921; (2) period of rapid spread, 1921–1931; and (3) period of equilibrium, 1931–1940. No reason has been found to explain why certain areas become static.

Primary roots of Deglet Noor palms were traced laterally from the trunk for a distance of 35 feet or more. Five orders of root branching were detected but no root hairs were observed, whereas a high percentage of roots were found in soil between 1 and 6 feet in depth. *Omphalia tralucida* was isolated in a severely affected palm only within a radius of 4 feet from the trunk and to a depth of 4 feet. The means by which omphalia spreads in the orchard from tree to tree has not been discovered.

New foci of disease are usually created by transplanting offshoots from diseased palms. Several instances are described where the disease was inadvertently spread from one planting to another by this means. Healthy offshoots of the Deglet Noor variety became badly diseased, and Khadrawy offshoots became only slightly injured when planted in infested soil. This gives some indication that the latter variety can be replanted in infested soil where soil disinfection is not practicable.

The occurrence of omphalia root rot may be prevented by the use of healthy offshoots in noninfested soil. There is observational evidence that the Khadrawy, Halawy, Iteema, Tazizaoot, Khustawy, Zahidi, and Tafazwin varieties and many seedlings possess considerable tolerance to the disease. Relative resistance of seedling palms increased with age. All the 18 horticultural varieties that were artificially inoculated under field conditions developed root lesions, but after four years no secondary symptoms had been observed.

In soil treatments with potted date seedlings, 17 chemicals were used representing the hydroxides, nitrates, sulfates, and phosphates of hydrogen, potassium, ammonium, and calcium. Treatments with the ammonium compounds resulted in the lowest percentages of aborted roots, and treatments with the calcium compounds resulted in the highest percentages. The nitrates as a group gave the most effective control of the disease; the phosphates were least effective and, in fact, seemed to increase the severity of attack. Ammonium sulfate reduced infection when applied to soil 2 days after inoculation, but in

other treatments, when applied 3 to 6 months after inoculation, it did not check the development of the disease.

The health of many slightly affected palms in one date garden was improved by heavy applications of water and fertilizer. Among 68 other palms whose condition was either unchanged or worse, were the severely affected palms which for years had been stunted and worthless. Although the benefits of good cultural management were clearly evident in slightly affected palms, there was no practical evidence of recovery of very sick palms.

Carbon disulfide, chloropicrin, and ethylene oxide gave the most encouraging results in preliminary experiments on soil disinfection against omphalia. All were effective in killing the pathogen and all produced slight to marked stimulation of growth in cauliflower seedlings planted 30 to 46 days after treatment to test the effect of the chemicals on the soil. Under field conditions, however, carbon disulfide was judged to be the most satisfactory. The method of application is described.

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PLATES



Plate 1.—Necrotic lesions of omphalia root rot in roots of the Deglet Noor variety: *A*, longitudinal section through the root zone of a palm, showing primary symptoms of the disease in the trunk and in young roots which are penetrating the fungus-infested bases of dead leaves; *B*, oblique sections through two primary roots, showing the appearance of a healthy root (*a*) and a diseased root (*b*); C, a young, aborted root; *D*, longitudinal section through diseased roots, showing typical necrosis and rot of the tissues.

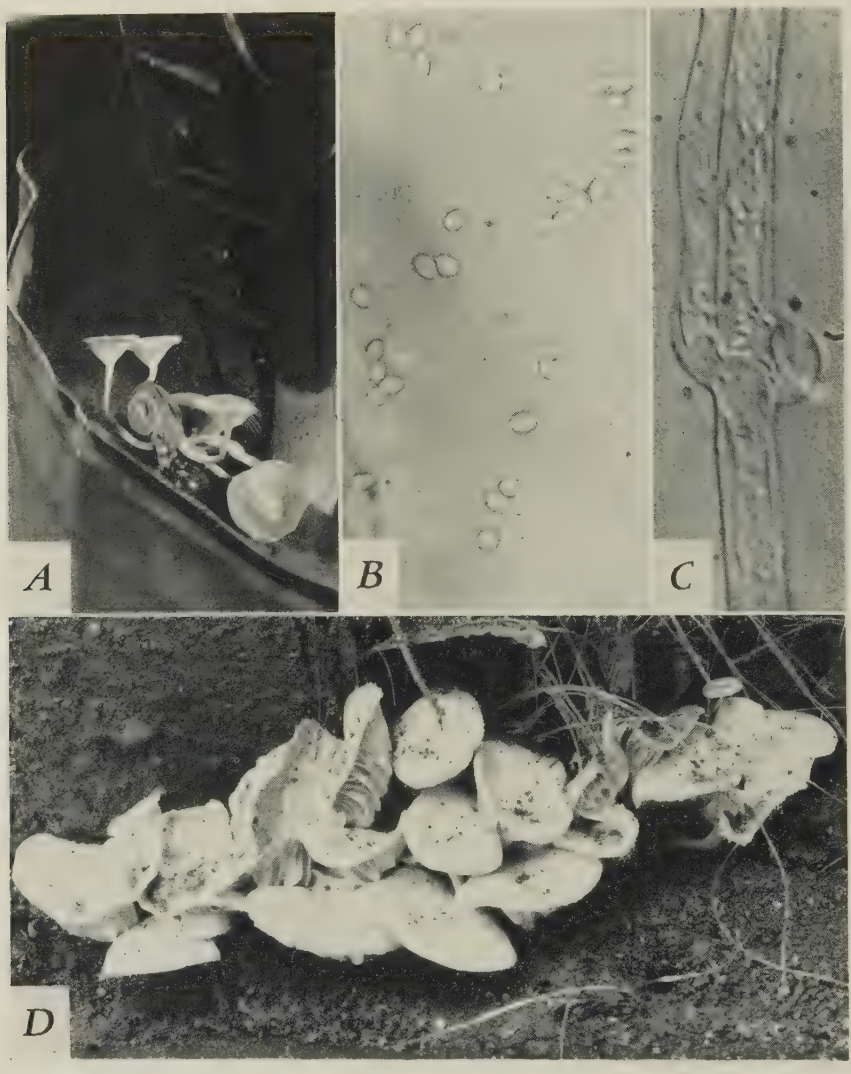


Plate 2.—*Omphalia pigmentata*: *A*, sporophores produced on *Phoenix dactylifera* under artificial conditions (×0.78); *B*, basidiospores (×533); *C*, branched mycelium with clamp connections (×1182); *D*, group of sporophores produced on a Saidy date palm under natural conditions (×0.86).

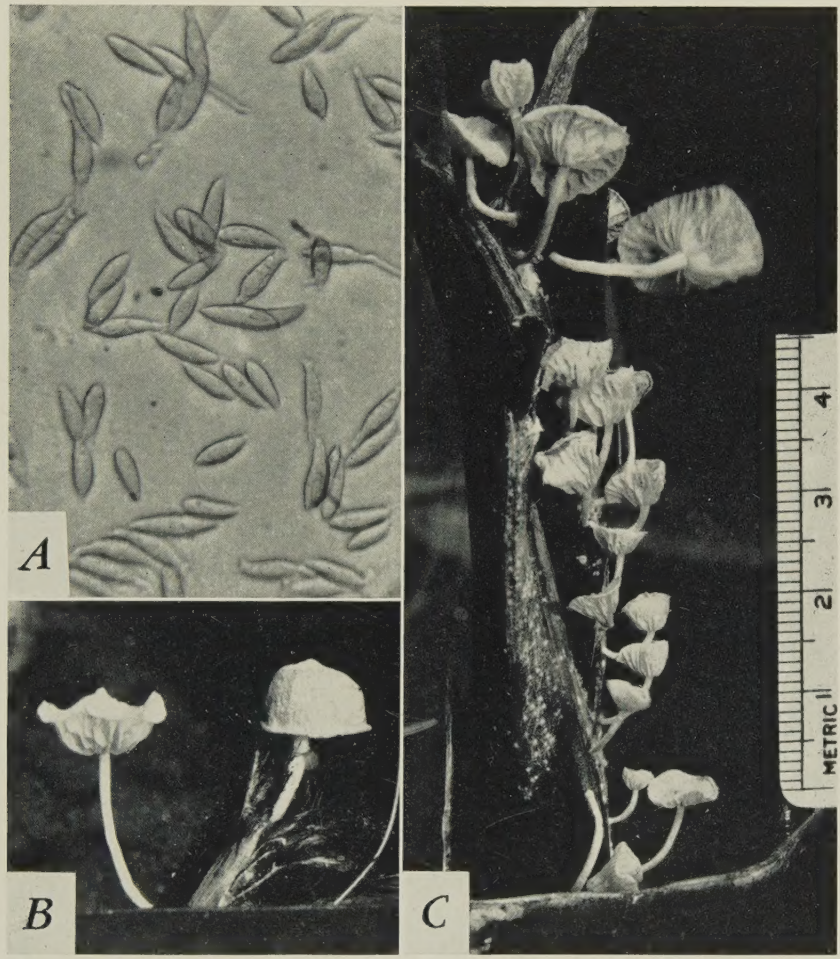


Plate 3.—*Omphalia tralucida*: *A*, basidiospores, some of which have germinated (×612); *B* and *C*, sporophores on *Washingtonia filifera*, produced under artificial conditions.

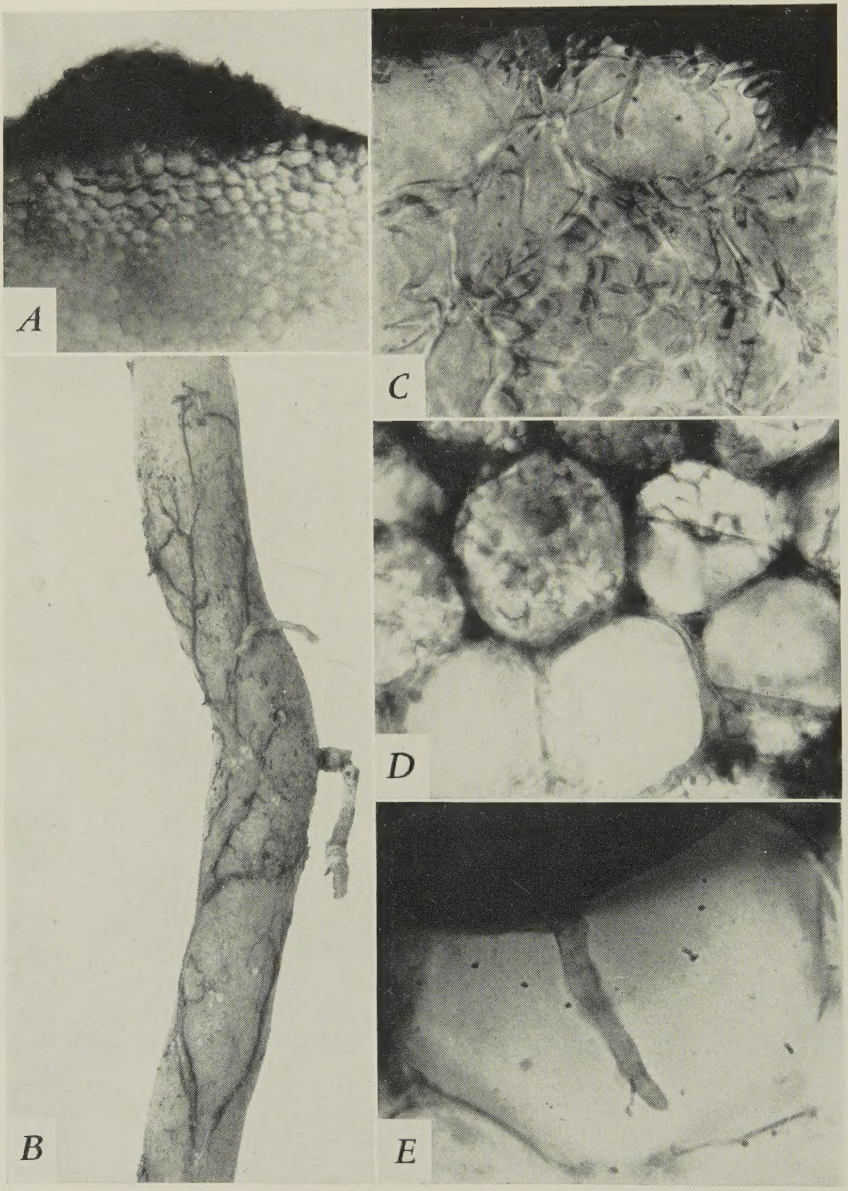


Plate 4.—Mycelial penetration of a date root by *Omphalia tralucida*. *A*, Transverse section of a rhizomorph attached to the surface of the root (× 114); *B*, branched rhizomorphs on the surface of a root (× 2); *C*, mycelial invasion of cortical cells (× 480); *D*, dead cortical cells filled with mycelium (× 480); *E*, hyphal tip entering a cortical cell (× 1033).

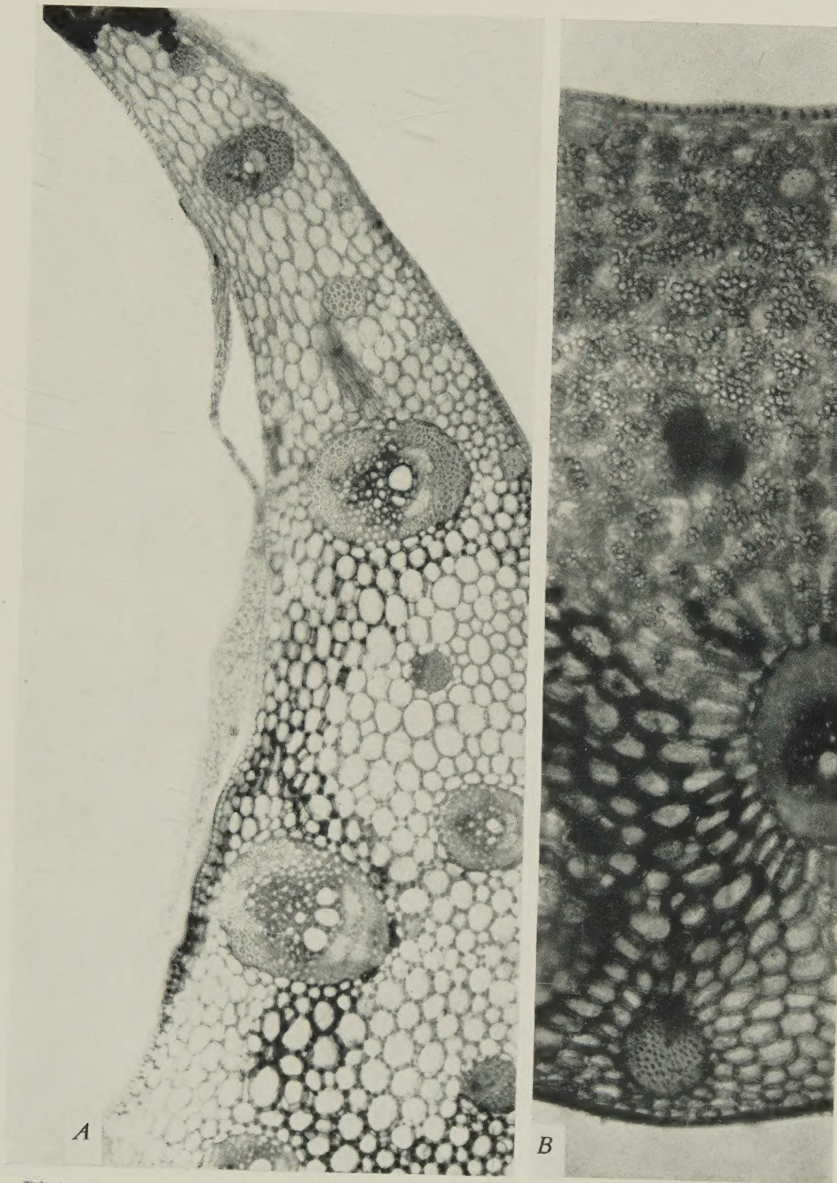


Plate 5.—Compound photomicrographs showing the effect of *Omphalia tralucida* on leaf tissues of the date palm prior to mycelial invasion. *A*, Transverse section of seedling leaf with brownish discoloration of parenchyma cells beneath a mycelial mat (×78); *B*, discoloration of tissues and the digestion of starch grains from a seedling leaf which is shown in transverse section (×78). Material fresh and not stained.

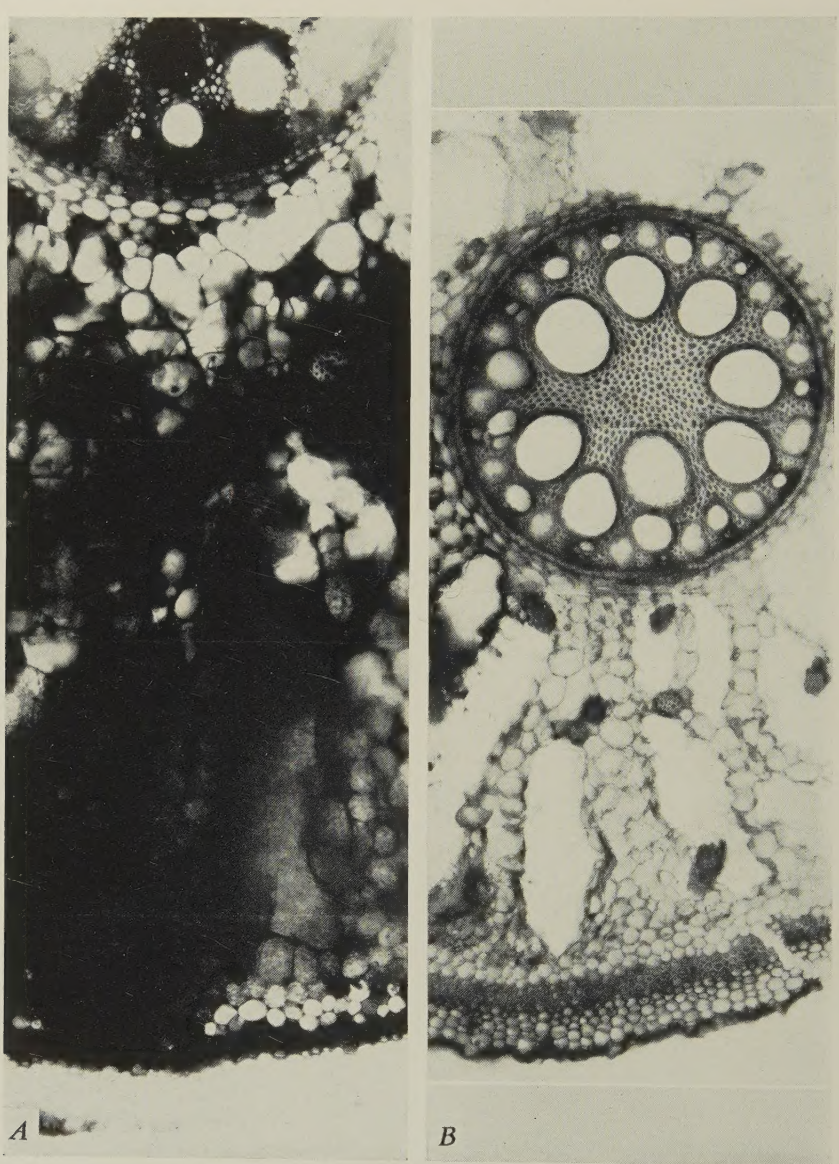


Plate 6.—Compound photomicrographs showing portions of date roots in transverse section. *A*, Diseased root with mycelial masses of *Omphalia tralucida* within the cells and cavities of all tissues from the outer integument to the xylem ducts (× 86); *B*, a healthy root (× 86). Material fresh and not stained.